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GEOLOGY AND MINERAL DEPOSITS OF THE KANTISHNA HILLS, MT. McKINLEY QUADRANGLE, ALASKA

A

Thesis

Presented to the Faculty of the University of Alaska

in Partial Fulfillment of the Requirements

for the Degree of

Master of Science

By

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Fairbanks, Alaska

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GEOLOGY AND MINERAL DEPOSITS OF THE KANTISHNA HILLS,

MT. McKINLEY QUADRANGLE, ALASKA

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ABSTRACT

The Kantishna Hills are located on the north flank of the Alaska Range, 150 km southwest of Fairbanks, Alaska. The layered rocks consist of four sequences of regionally metamorphosed rocks ranging in age from Precambrian to Mississippian. The Birch Creek Schist is a polymetamorphic unit that has been metamorphosed to the amphibolite facies and later retrograded to the greenschist facies. The low grade, regionally metamorphosed Spruce Creek Sequence, Keevy Peak Formation, and Totatlanika Schist of Paleozoic age are tectonically juxtaposed against the Birch Creek Schist.

Undeformed mafic to felsic dikes of Tertiary age intrude the crystalline schist terrane. Miocene sediments and Quaternary deposits overlie older lithologies. The region has been successively deformed by isoclinal to open folds, and faults.

The Kantishna Mining District is known for polysulfide vein-faults and placer gold deposits. Hydraulic fracturing of metalliferous host rocks during deformation probably controlled the Kantishna vein system.

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SCOPE OF PRESENT INVESTIGATIONS

This report summarizes a geologic mapping and resource assessment program of the Kantishna Hills, located 150 km southwest of Fairbanks, Alaska (fig. 1). Geologic mapping of approximately 1,780 km^2 (700 mi^2) was completed at 1:63,360 (inch to the mile) scale. In response to state land selection interest in the area, a mineral resource investigation was undertaken by the Alaska Division of Geological and Geophysical Surveys (ADGGS) under the direction of Dr. T. E. Smith. Smith later delegated full responsibility of the project to the author. The geologic map (pl. 1) is the result of mapping by T. K. Bundtzen, with valued assistance from T. E. Smith, R. M. Tosdal, J. E. Decker, C. L. Daniels, J. T. Kline, G. M. Laird, and G. F. Ferrell, as well as use of selected data from studies by White (1942), Reed (1961), Morrison (1964), and Hawley (1977). Field work was conducted in June, July, and August of 1975, July and August of 1976, one week in August of 1978, and 3 weeks in July of 1979. Most mapping was completed on foot from camps on Chitsia, Stampede, Crooked, Caribou, Moose, Moonlight, and Marten Creeks and Bearpaw River. D. L. Turner of the University of Alaska Geophysical Institute joined the field party in August 1975 and collected samples for K-Ar dating, the results of which have been published elsewhere (Bundtzen and Turner, 1979).

Bedrock information on plate 1 is limited by relative bedrock exposure and mapping coverage. The most poorly exposed areas are in the west-central Kantishna Hills from Rock Creek north to Flume Creek and the heavily vegetated hills west of the Toklat River northeast of the

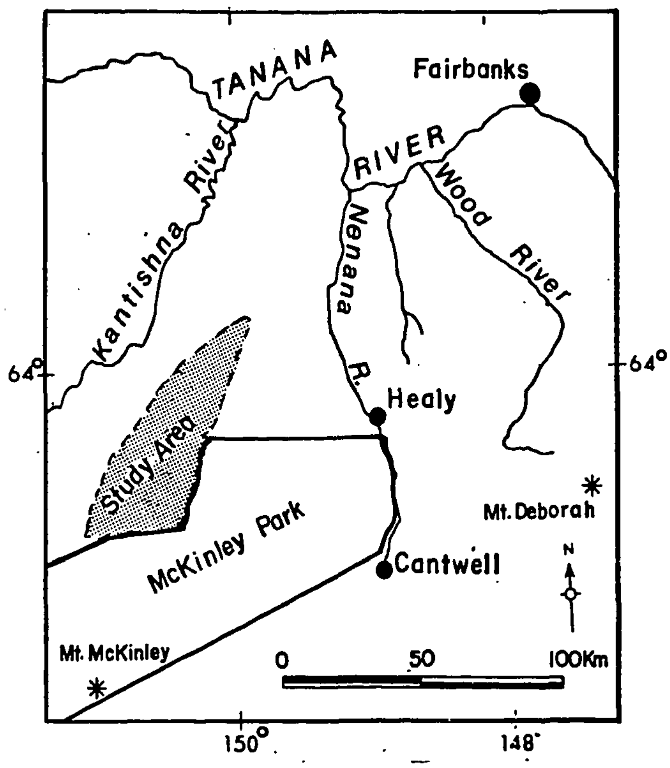


Figure 1. Location of study area, Kantishna Hills, Alaska.

Crooked Creek drainage. Most of the remaining hills provide adequate exposure for 'inch-to-the-mile' mapping.

Approximately 400 rock thin sections and 60 polished sections of specimens from mineral deposits were examined using transmitted and reflected light respectively. Maps of prospects and mines by the author and those modified after Wells (1933), Pilgrim (1929), and Hawley (1977) have been incorporated into the study.

In this report, linear dimensions and weights have been expressed in the metric system; however, the English system has been retained for altitudes due to the existing (1:63,360) topographic base. During the discussion of the geologic units, the reader is referred to the geologic map (pl. 1).

ACKNOWLEDGMENTS

Besides those individuals previously acknowledged for field assistance, the author is indebted to numerous individuals who assisted in both field and laboratory investigations. C. C. Hawley, E. R. Pilgrim, T. E. Smith, and W. G. Gilbert discussed various aspects of the project during the field research. M. A. Wiltse (ADGGS) performed timely and valuable major oxide analyses of metamorphic and igneous rocks. N. C. Veach (ADGGS) performed numerous mineralogical identifications of pan concentrates and provided garnet compositional estimates. James Bond (University of Alaska) performed X-ray analysis of alkali feldspars. D. R. Stein (ADGGS) assayed samples from mineral deposits. P. D. Rao (MIRL) and M. S. Robinson (ADGGS) assisted with ore microscopy techniques. R. B. Blodgett (Oregon State University) searched for conodonts and other fauna in metamorphosed limestone samples. R. D. Reger and J. T. Kline (ADGGS) offered helpful advice while the author was investigating the Quaternary geology of the region.

The author is particularly grateful to S. E. Swanson for important guidance and criticism during the metamorphic petrology phase of the research. Swanson, Smith, D. B. Stone, and C. L. Daniels edited the forthcoming prose. L. C. (Ann) Schell drafted plate 1 and several figures in the report. Penny Toston and Roberta Mann typed the numerous pages, figure captions, and tables of this report--their understanding during difficult times is appreciated.

The author expresses sincere thanks to the numerous miners and prospectors of the Kantishna Mining District, for their cooperation and permission to examine their mining properties. In particular, E. R. Pilgrim, L. M. Anthony, Paul and Eric Weiler, and James Fuksa shared their knowledge of the mineral resources of the region.

The author expresses appreciation to the National Park Service for allowing ease of access through then McKinley Park and permission to conduct research in the area. This project could not have been completed without the support and encouragement of W. G. Gilbert and R. G. Schaff (ADGGS)--to them, the author expresses his sincere gratitude.

PREVIOUS INVESTIGATIONS

Many geologic investigations of the Kantishna Hills have emphasized studies of mineral resources. Prindle (1907) first described early placer gold mining activity in the "Kantishna diggings" and gave thoughtful observations of the bedrock geology of the region. Brooks (1911) also described gold mining activity and metamorphic rocks of the Quigley Ridge area; Brooks (1916b) later summarized knowledge of antimony mineralization in the Kantishna district. The 'Mineral Resources of Alaska' series (U.S. Geological Survey Bulletins 379, p. 56; 442, p. 44; 520, p. 38; 542, p. 45; 592, p. 68; and 622, p. 65; contain brief summaries of mining activities in the Kantishna Region. Capps (1918) first provided descriptions of lode deposits of the area and information on mining, access, and geography; he later summarized his work in the area (Capps, 1940). Over the years, workers such as Davis (1922), Pilgrim (1929), Moffit (1933), Capps (1933), Wells (1933), Saunders (1964), Seraphim (1961, 1962), and Chadwick (1976) describe hard rock mineral deposits in the Quigley Ridge-Spruce Creek area while White (1942), and Barker (1963) report on the geology and mining activity at Stampede. Metz and Hawkins (1981), Glover (1948), Smith (1941) and Wimmler (1927) have provided gold fineness data from placer deposits.

Morrison (1964) completed the first petrographic study of metamorphic rocks in the Quigley Ridge region. Reed (1961) compiled a useful geologic map of the Mount McKinley Quadrangle using previous work and his own aerial photographic interpretation. Bundtzen, Smith, and Tosdal (1976), Bundtzen and Turner (1979), and Hawley (1977) updated information on the geology, geochronology, and mineral resources of the region.

GEOGRAPHY

The Kantishna Hills are a low rugged range of foothills separated from the higher terrain of the Alaska Range by the Clearwater Fork of Toklat River (pl. 1). The region is bordered on the west and northwest by the Kantishna-McKinley River basins. The study area ranges in altitude from 900 feet along the northern slopes of Chitsia Mountain to 4,982 feet on Kankone Peak in the southcentral portion of the hills.

The rugged nature of the Kantishna Hills is, in part, a result of rapid uplift during late Quaternary time. The northeasterly trend of the region parallels the structural grain of basement metamorphic rocks. Headwater portions of streams such as Glacier, Rock, Caribou, and Flume Creeks flow in rugged "V-shaped" canyons and parallel the northeast-southwest bedrock structural grain; they swing north into broader meandering valleys subsequent to leaving the hills (fig. 2). Because of lack of present glacial sources, all streams originating in the Kantishna Hills run clear except during times of temporary siltation due to torrential flooding, spring runoff, and placer gold mining activity.

A near-horizontal, regional, 60-km^2 surface, here referred to as the 'Crooked Creek Plateau', caps the hills north of Crooked Creek (fig. 3). The surface truncates structure in the underlying rocks and has been partly dissected by stream downcutting. It shows similarities to surfaces described by Wahrhaftig and Black (1958) near Rex Dome, Mt. Wright, and in the Teklanika River areas of the Healy Quadrangle, and the Macomb Plateau near Johnson River (Holmes and Foster, 1968), which have been variously interpreted as (1) late Cenozoic preglacial Pediment surfaces (2) strath terraces formerly underlain by Tertiary rock, or (3) surfaces

Figure 2. "V"-shaped canyon profile of upper Caribou Creek, looking east.

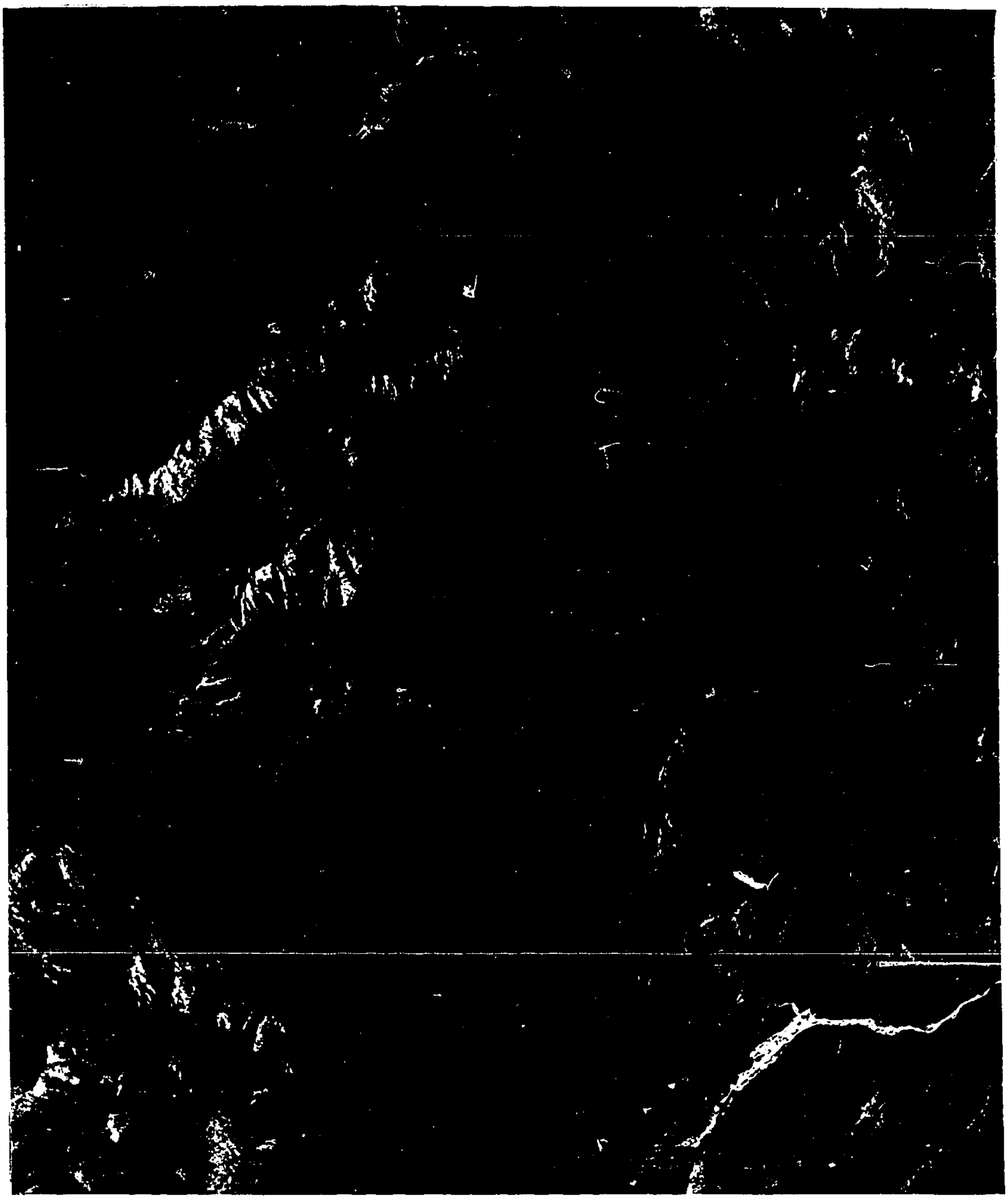


Figure 3. 1:40,000 scale airphoto of Crook Creek Plateau, central Kantishna Hills, Alaska.

carved by ice sheets. No glacial erratics or deposits of glacial origin have been recognized on the Crooked Creek Plateau. Although broad areas due west of the Kantishna Hills appear flat from a distance, they are composed of low hills, numerous lakes, thermokarst pits, and depressions up to 3 km in diameter.

Timberline varies from 1900-2500 feet in elevation and reaches maximums in the hills west of the Toklat River and in sheltered valleys of the Canyon Creek drainage. Vegetation consists of white and black spruce sometimes intermixed with alder in areas with adequate drainage. Widely scattered birch and aspen stands occur in very well drained south facing hills. Thick patches of willows and alders grow on active flood plains and in areas of former placer mining activity. Moist tussock tundra covers broad, near-horizontal surfaces underlain by Tertiary sedimentary rocks and other poorly drained areas.

The climate is generally continental but varies somewhat from north to south due to the orographic influence of the Mt. Denali rain shadow (fig. 4) and gradual gain in elevation from north to south. The mean daily minimum temperature in January varies from -22° to -30° north to south, while the mean daily maximum temperature in July is +20 degrees Celsius. Average annual rainfall varies from 40 to 50 cm north to south (Wahrhaftig, 1965). Permafrost is extensive and absent only in active flood plains and on south facing slopes.

A secondary road, the Denali Highway, continues from Wonder Lake for 10 km to the Friday Creek airstrip on the flood plain of Moose Creek. Approximately 40 km of unmaintained roads and ATV trails branch off from

Figure 4. View of Denali from Crooked Creek, central Kantishna Hills.

this road and provide access to mines and prospects on Glacier, Caribou, Glenn, Spruce, Eldorado and upper Eureka Creeks. A winter trail 90-km-long was constructed in 1936 from Kobe on the Alaska Railroad to Stampede to haul out high grade antimony ores from the Stampede Mine. Portions of this trail were improved in 1960 by the Alaska Road Commission to provide a transportation corridor into the Kantishna Mining district; however, construction work was eventually suspended and it remains partially overgrown and unused by miners. Unimproved airstrips include those at Stampede, Friday Creek and Crooked Creek. As in many other portions of Alaska, the Kantishna region is relatively inaccessible. Principal human activities have been mining, trapping, hunting, tourism and recreation.

GEOLOGIC UNITS

Birch Creek Schist

Introduction

Spurr (1898, p. 140-145) originally classified regionally metamorphosed quartzite and micaceous schists exposed in the 'Birch Creek District' (now the Circle mining district) in the Yukon-Tanana Upland north of the study area as the 'Birch Creek series', and overlying marble, quartzite, garnetiferous schist, and amphibolitic schists as the 'Fortymile series.' Eventually, workers began to use the term 'Birch Creek Schist' to denote all regionally metamorphosed rocks in the interior of Alaska. Mertie (1937, p. 48) restricted the term 'Birch Creek Schist' only to those metamorphic rocks that he regarded as Precambrian in age. In addition, he specified that they characteristically underwent more than one period of regional dynamothermal metamorphism.

Brooks (1911b) and Prindle (1907) correlated metamorphic rocks of the Kantishna Hills with the Birch Creek Schist. Later, Capps (1918, 1940), Moffit (1933), Wells (1933), White (1942), and Reed (1961) mapped metamorphic rocks cropping out in the Kantishna mining district as Birch Creek Schist. Although Wells (1933) and Morrison (1964) both recognized several distinctive lithologies in the Quigley Ridge area, they described all metamorphic rocks they studied as Birch Creek Schist. In this study some of these metamorphic rock lithologies have been assigned differing metamorphic facies, composition, and age.

Clearly, problems have arisen with the use of the all-inclusive term Birch Creek Schist for interior Alaska metamorphic belts, and workers such as Wahrhaftig (1968), Gilbert and Redman (1977), Gilbert (1976), Hickman and others (1977), and Gilbert and Bundtzen (1979) have subdivided the metamorphic rocks of the north-central Alaska Range into lithologies of several different ages. Foster and others (1973) have suggested that the term 'Birch Creek Schist' be abandoned. In this report, however, the author informally retains a modified Mertie (1937) definition of the Birch Creek Schist in the Kantishna Hills for those metamorphic rocks that form 'basement' based on stratigraphic relationships and that have undergone two or more periods of recrystallization. Most thin sections of these polydeformed rocks show evidence of an upper greenschist-to-amphibolite facies prograde event that has undergone a cycle of retrogressive metamorphism under conditions that reached lower greenschist facies. Six units of Birch Creek Schist mapped during this study include: greenstone and greenschist (pCg), undifferentiated quartzite and quartz mica schist (pCs), graphitic schist (pCgs), porphyroclastic quartzo-feldspathic schist (pCfs), calcareous schist (pCcs), and marble (pCm). These rocks contrast in composition and metamorphic history with the younger Spruce Creek Sequence, Keevy Peak Formation, and Totatlanika Schist, which have undergone only one well recognized episode of low-grade, regional metamorphism.

Undifferentiated pelitic schist and quartzite (pCs)

Interbedded micaceous quartzite, porphyroclastic quartzite and pelitic schist, of the pCs unit form the most widely distributed map unit in the Kantishna Hills. The micaceous quartzite is light to medium gray, limonitically stained, fine and medium grained and usually form bold, resistant, blocks on ridges due to its high quartz content.

Brownish to gray, medium grained, interbedded pelitic and minor quartzo-feldspathic schists form non-resistant outcrops in saddles and along rounded subdued ridges. Schistosity is defined by the parallel orientation of mica flakes, but secondary 'S' surfaces defined by slip cleavage are common in the pelitic and quartzo-feldspathic schists. All pCs lithologies are characteristically isoclinally deformed; fold amplitudes range from 1 to 50 m (fig. 5).

In thin section, micaceous quartzite is seen to be composed of 70-90 percent interlocking quartz grains from 0.2 mm to 3 mm long with variable amounts of pleocroic green and brown biotite + white mica ± oligoclase + albite ± chlorite ± calcite and trace amounts of garnet, sphene, and tourmaline. Small, euhedral garnets about 0.2 mm in diameter have been largely altered to chlorite, feldspar, and opaque minerals. Micaceous quartzites tend to have the same relative mineralogies as the more pure varieties described above but, with relative increases in the white micas, biotite, chlorite, and garnet porphyroblasts.

Some varieties of quartzite and impure quartzite contain angular porphyroclasts of bluish quartz and plagioclase feldspar. The most conspicuous exposures of these porphyroclastic quartzite occur near Stampede, east of Kankone Peak, and on Eldorado Creek; they are noted 'gr' on plate 1. In thin section the matrix of these rocks is composed of approximately 75-80 percent xenoblastic interlocking quartz grains, 10 percent brown biotite and muscovite, and 10 percent undetermined feldspar and accessory tourmaline and sphene. The trimmed feldspar and bluish quartz porphyroclasts are up to 5 mm in diameter, have a preferred

Figure 5. Isoclinally folded quartzofeldspathic schist, (pCs unit), Crooked Creek area (75 Ast 1598).

orientation parallel to schistosity, and have been recrystallized during metamorphism. These quartzites are probably recrystallized sandstones or pebble conglomerates with porphyroclasts being relict sedimentary grains.

Interbedded pelitic and quartzo-feldspathic schists are composed of relict oligoclase + albite + zoisite or clinozoisite + chlorite + white mica + pleocroic brown to green biotite ± garnet ± calcite. Accessory yellow-green tourmaline, sphene, and zircon, are ubiquitous in most thin sections. Most of the rarely twinned plagioclase grains examined are albite, but a few grains in many sections appear to be oligoclase (An 17-25) that often contain an 'S' surface (incipient cleavege) which transects prevailing schistosity. Oligoclase usually occurs in complex aggregates of quartz, albite, mica (usually chlorite), and zoisite. Within these aggregates, the oligoclase and quartz are inclusion charged with zoisite, appear trimmed and sheared, and are probably relict from an earlier metamorphism (fig. 6). Thus, the albite and zoisite-clinozoisite are believed to be recrystallization products of the oligoclase. Some of the albite, however, also contains inclusions of zoisite-clinozoisite, but the epidote minerals are believed to be in equilibrium with the albite.

Many pelitic schist samples contain subhedral-to-euhedral garnet porphyroclasts up to 2 cm in diameter that comprise 5-15 percent of the rock. Garnet porphyroblasts exhibit all degrees of retrograding ranging from thin chlorite jackets to relict atoll structures to complete pseudomorphs composed of a variety of clinozoisite, chlorite, opaque minerals and undetermined feldspar (fig. 7a-c). Some garnet porphyroblasts display

Figure 6. Trimmed and sheared relict oligoclase grain in pCs unit partially absorbed by albite (75 Ast 2623.1).

(a) (b) (c)

Figure 7a-c. Photomicrographs of garnet porphyroblasts in pCs unit showing effects of progressive retrograde metamorphism. a) Garnet rimmed with chlorite jacket under crossed nicols; note rotated S_1 surface (75 Ast 2597.5). b) Garnet with retrograde atoll microstructures (75 Ast 1590) in plane light. c) Garnet pseudomorph after chlorite, biotite, and opaque alteration products in plane light (75 Ast 1592).

a rotated 'S' surface that has been preferentially replaced by chlorite and opaque minerals. Most pelitic schists contain 40-75 percent mica as large flat grains, trains, and layers parallel to schistocity. These are usually the white micas phengite and/or muscovite with subordinate pennine chlorite and pleocroic dark reddish brown to straw yellow biotite. The presence of the two white micas in the same samples may indicate a more advanced metamorphic grade for the more 'ideal' muscovite and a 'lower grade' of formation for the phengite. Chlorite appears to be in textural equilibrium with the brownish tinged phengitic white mica, but seems to replace the ideal white micas with a lower refractive index.

Alkali feldspar, when present, consists of small anhedral, locally polysynthetically twinned (albite and periclase twinning) grains interstitial to quartz and other feldspars.

Graphitic schist (pCgs)

Discontinuous, dark gray, fine to medium grained, limontite stained graphite schist and phyllite crop out in an irregular belt from Crooked Creek to Rock Creek. Although these graphitic schist layers are complexly folded and difficult to map along strike, they served as valuable marker beds in the Birch Creek Schist. Near Crooked Creek, the pCgs bands are isoclinally repeated and provide a structural signature for the Birch Creek Schist.

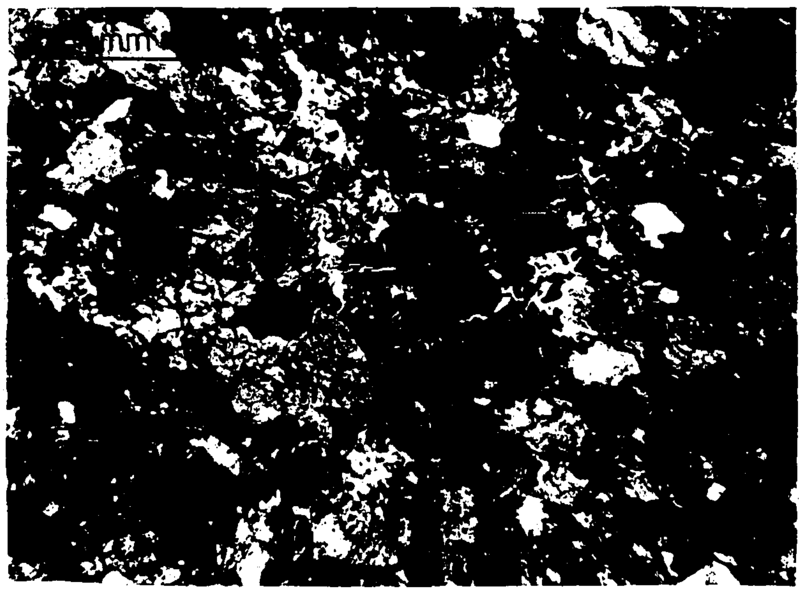
Mineral assemblages observed in thin section are similar to those observed in pelitic schist of the pCs unit with the addition of graphite--namely xenoblastic quartz + white mica + biotite + albite ± relict oligoclase + chlorite + zoisite ± actinolite ± tourmaline ± sphene. Some varieties grade into light greenish gray, chloritic phyllite. Field-identified graphite is actually segregations of dark brown biotite, chlorite, and graphite.

Amphibolite and greenschist (pCg unit)

Medium to dark green, garnetiferous greenstone, well foliated amphibolite, and chlorite-rich amphibolitic greenschist crop out in the Quigley Ridge area, near Kankone Peak, and in the upper Bearpaw River-Crooked Creek region. Textures in these rocks range from fine grained, well foliated greenschist to nearly massive, unfoliated, coarse-grained greenstone (fig. 8a). Examination of 36 thin sections demonstrate that almost everywhere, mineral assemblages in disequilibrium can be recognized.

The pCg unit is composed of garnet, hornblende and/or actinolite + chlorite + biotite + epidote + zoisite + locally abundant sphene, + plagioclase (usually albite) + white mica + quartz + zircon, and ± tourmaline. Garnet, which comprises 2-15 percent of the rock, occurs as pinkish-brown, subidioblastic-to-idoblastic porphyroblasts ranging from < 0.5 mm to 3 mm in diameter and usually is sheathed in chlorite-limonite selvages. Garnet porphyroblasts exhibit all degrees of retrograde metamorphism grading from thin chlorite jackets to relict garnet atoll structures charged with zoisite, biotite, feldspar, and chlorite to complete pseudomorphs of garnet composed of a variety of the previously mentioned replacement minerals (fig. 8b). Some specimens show a relict S_1 fabric transposed by later S_2 cleavege. Epidote is colorless to dull green and occurs as interlocking granular aggregates comprising 5-40 percent of specific samples. Clinozoisite and/or zoisite are ubiquitous to all specimens examined and occur as anhedral shaped inclusions in plagioclase,

a



b

Figure 8a-b. a) Amphibolite lens (75 Ast 1991) enclosed in micaceous-feldspar schist of pCs unit, Wickersham Dome. b) Photomicrograph showing (h) hornblende (g) garnet (b) biotite and (c) clinozoisite crossed nicols, (75 Ast 1991).

garnet, epidote, and locally amphibole. Hornblende typically occurs either as nondirectional equant grains up to 8 mm long or flattened elongate grains that parallel the foliation. In both cases hornblende is partially to extensively replaced by biotite, chlorite, and epidote. Actinolite, biotite, and chlorite occur as primary pleocroic elongate porphyroblasts or as replacements of hornblende or garnet (fig. 8b). Plagioclase is normally present as helicitic, untwinned albite xenoblasts up to 2 mm in diameter but in a few samples, faintly twinned crystals range in composition from An_{15}-An_{22} which suggests that relict oligoclase occurred in a prograde metamorphic event. Other minerals include abundant sphene, quartz, calcite, zircon, ± tourmaline, sphene and calcite.

Three of four chemical analyses of amphibolite of the pCg unit in table 1 plot in the tholeiitic field of an AFM diagram (fig. 9). Three of the four samples, plot in the subalkaline field of an alkali-silica diagram (fig. 10). Overall, their Na_2O, K_2O, and TiO_2 contents are similar to those found in mid-ocean ridge environments (Irvine and Barager, 1971; Sun and Nesbitt, 1978). These data support the contention that many massive garnet amphibolites of the pCg unit are metabasic igneous rocks; it is emphasized that chemical composition may have changed during regional metamorphism.

Quartzo-feldspathic schist and gneiss (pCf)

Light tan, medium grained, semischistose to massive, mica-bearing quartzo-feldspathic schist and gneiss form a northeast trending belt of rocks trending from the Bearpaw River to the headwaters of Bear Creek. Contact relationships of this unit with enclosing mica rich schist and quartzites of the pCs unit are not well understood and approximately

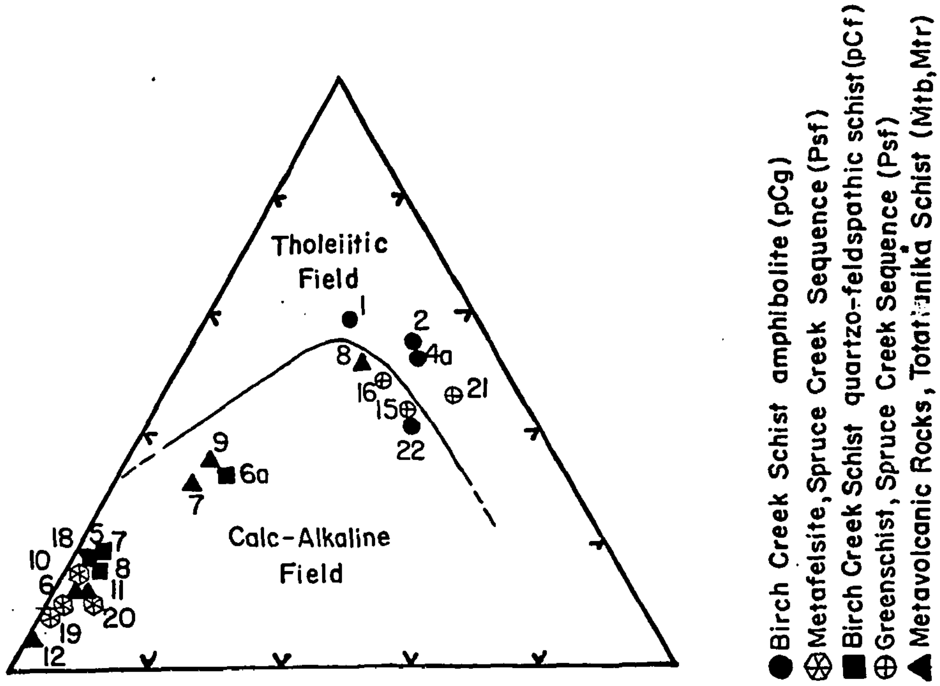


Figure 9. AFM projection of meta-igneous rocks in the Kantishna Hills.

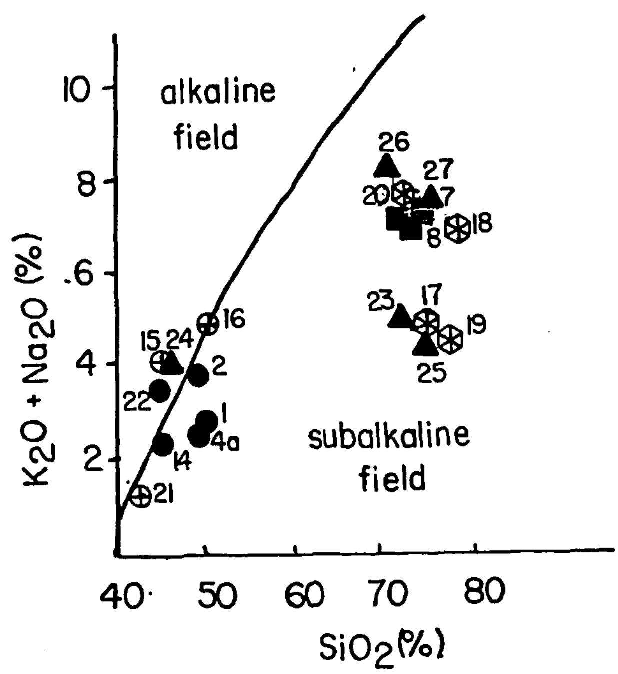


Figure 10. Alkali-silica diagram of meta-igneous(?) rocks, Kantishna Hills.

shown on plate 1. These rocks are very resistant and form large equant blocks on hillsides and in talus slopes that resemble granitic intrusive rubble from a distance.

In thin section these rocks are composed of porphyroclastic coarse grained, xenoblastic quartz, albite, and alkali-feldspar grains with interstitial white mica and highly pleocroic, olive-reddish brown biotite (fig. 11a). Relicts of large anhedral, trimmed oligoclase grains 5 mm long roughly parallel the metamorphic fabric but are locally discordant; this gives the illusion of a porphyritic igneous texture. Conspicuously dusty, undetermined feldspar flecked with sericite comprises up to 50 percent of many samples. Ubiquitous grid twinned alkali feldspar comprises up to 20 percent of observed samples (fig. 11b). Other minerals include zoisite, tourmaline, sphene, and rare garnet. The scarce nature of garnet in pCf versus its relative abundance in other Birch Creek Schist lithologies is probably the result of compositional differences rather than differing conditions of regional metamorphism. A plot of three chemical analyses of pCf lithologies from table 2 on an AFM projection (fig. 9) and alkali-silica diagram (fig. 10) demonstrate the chemical similarities of these metafelsic rocks to calc-alkali granite and ademellite reported by Nockolds (1954).

Magnetite bearing, epidote rich, regionally metamorphosed garnet-amphibolite forms along contact zones of the pCfs unit (cross hatched on pl. 1). These amphibolites have a subschistose texture of hornblende and quartz-feldspar-mica bands parallel to foliation. Euhedral outlines of blue-green, carlsbad twinned actinolite (x = bluish green, y = olive green, z = turquoise) grains are essentially nondirectional but largely

a

b

Figure 11a-b. Textural variants of quartzofeldspathic gneiss in Crooked Creek area a) gridiron-twinned, alkali feldspar grain from quartzofeldspathic gneiss, pCf unit (crossed nicols; 75 Ast 1297); (b) large alkali feldspar grain in porphyroblastic metafelsite (crossed nicols; 76BT203).

overprinted by epidote group minerals, undetermined feldspar, chlorite, and opaques. Garnet makes up to 50 percent of some samples, and is usually jacketed and veined with chlorite. Many garnets display relict oscillatory zoning. Almost 30 percent of the matrix in most samples consists of aggregates and amorphous masses of epidote group minerals.

Because of suspected relict igneous texture (blastoporphyritic, albite, and K-feldspar grains) similarities of major oxide chemistry to felsic igneous rocks, locally discordant contacts with enclosing schists, and apparent relict hornfels or skarns developed adjacent to contacts, the pCf unit is believed to represent a belt of metai-gneous felsites that intruded and/or extruded prior to the initial regional dynamothermal metamorphic event.

Calcareous schist (pCc) and marble (pCm)

Light greenish-gray, distinctly limonitically stained, calcareous mica schist, impure marble, and micaceous quartzite of the pCc unit crop out on resistant hilltops near Stampede and southeast of the headwaters of Moonlight Creek. These calcareous rocks grade into the pCs unit, particularly in the eastern part of the study area.

Light gray, bleached, coarse grained, discontinuous, micaceous marble (pCm) lenses up to 50 m thick form a conspicuous but minor part of the Birch Creek Schist complex in the central Kantishna Hills. This unit locally grades into the calcareous schist unit (pCc). Individual calcite and scattered grains are generally visible in hand speciman, which gives these rocks a molted, sugary appearance.

Texturally, the pCm and pCcs units contain bands of dominantly calcite interspersed with isolated quartz grains or alternatively, layers and lenses of interlocking quartz-graphite aggregates up to 1 cm thick that may represent relict sedimentary clasts. The quartz and mica content in all thin sections examined from pCcs and pCm units varies from 2-10 percent each and the parent rocks were probably siliceous and pelitic limestones. Four of six thin sections from both units are composed of 70-80 percent calcite, 2-10 percent quartz, and the remainder as ± phlogophite, ± graphite, + albite + epidote + white mica ± chlorite and undetermined feldspar and opaque minerals. Albite in the thin sections establishes the metamorphic grade as the greenschist facies (Turner, 1968, p. 279).

One thin section from a pCm marble sample on Crooked Creek contains calcite + plagioclase + tremolite + diopside + zoisite + tourmaline + quartz, all of which appear to be in textural equilibrium. This assemblage is compatible with an amphibolite or hornblende-hornfels facies for calcareous rocks as described by Thompson (1957) and Turner (1968).

Metamorphic summary

The Birch Creek Schist in the Kantishna Hills is believed to be a thick wedge of metasandstone and minor pelitic metasedimentary rocks with intercalated metabasic igneous sills and flows and marble that has undergone at least two periods of recrystallization. Mineralogical, textural, and radiometric age evidence indicates a complex polymetamorphic history for the Birch Creek Schist. In most thin sections, mineral assemblages in disequilibrium can be recognized. Mineralogical criteria shows that a prograde mineral assemblage has been subjected to a cycle of retrogressive metamorphism as summarized below:

(1) Relict oligoclase/calcic plagioclase replaced by albite + zoisite.

(2) Garnet replaced by chlorite and/or biotite opaque minerals + undetermined feldspar.

(3) Hornblende replaced by actinolite and/or tremolite + biotite + chlorite.

(4) Relict biotite replaced by pennine-magnetite(?) or pennine-rutile(?).

(5) 'Ideal' muscovite replaced by phengitic white mica.

(6) Orthoclase(?) replaced by alkali feldspar, possibly microcline.

The characteristic prograde and retrograde mineral assemblages present in the different rock types are shown in table 2. The mineral assemblages from different lithologic variants are shown on ACF-A'KF, AFM, and CaO-SiO_2-MgO diagrams (figs. 12-14); these illustrate the tie line relationships between the prograde and retrograde events.

Biotite, white mica, sphene, tourmaline, and quartz in mineral assemblages in table 2 probably coexisted during the prograde and retrograde recrystallization events, although it seems likely that the micas changed chemical composition.

Utilizing criteria established by Strek (1969) and Wenk and Keller (1969) the appearance of hornblende and calcic plagioclase (An > 17) in basic rocks designates the amphibolite facies of metamorphism; these minerals are present in amphibolites and greenschist of the pCg unit in the northwest and central portions of Kantishna Hills. Prograde mineral assemblages in pelitic and quartzo-feldspathic schists (pCs) and in the quartzo-feldspathic schist and gneiss (pCf) are compatible with the amphibolite facies designation in the central and northwestern portion

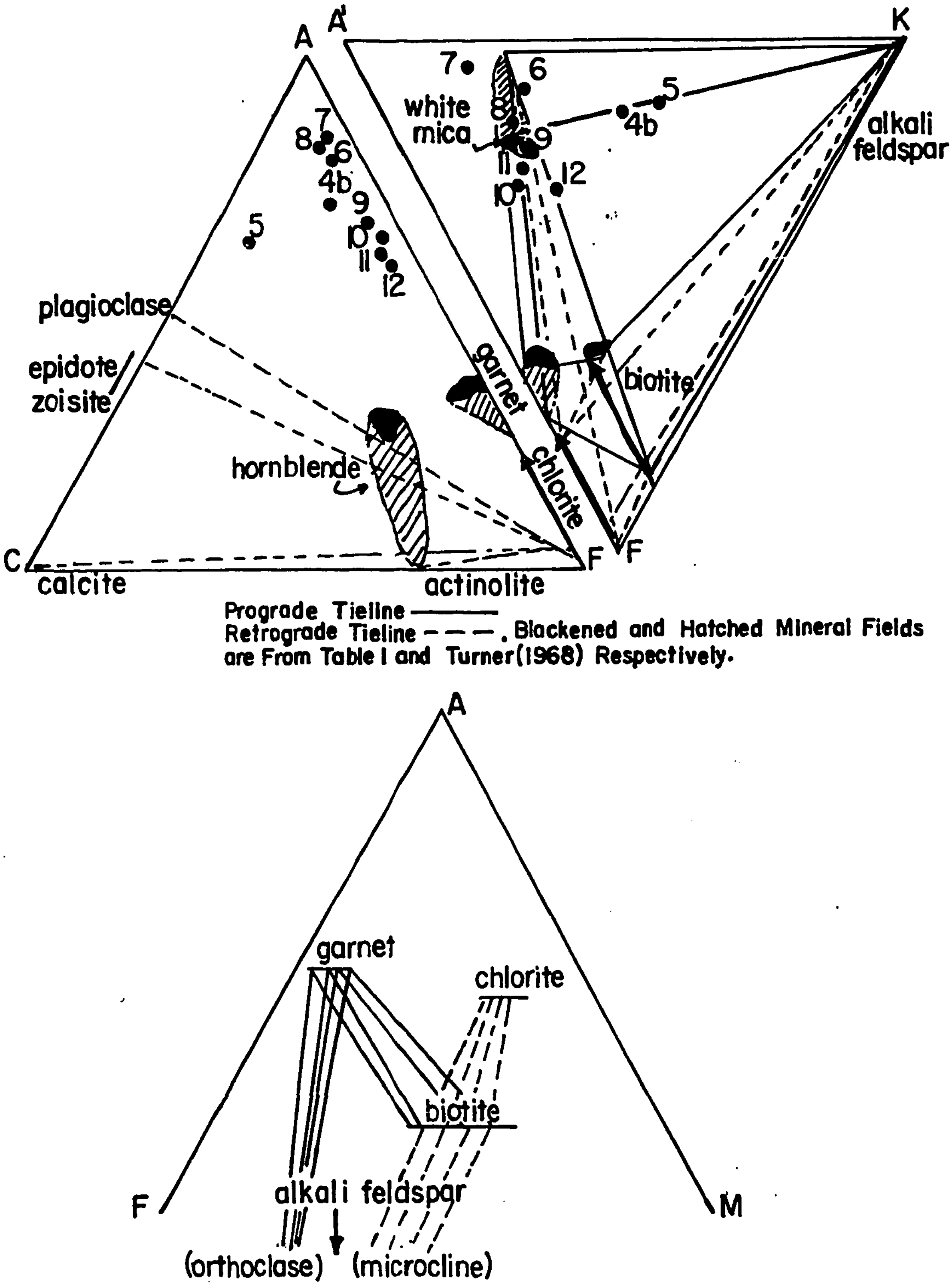
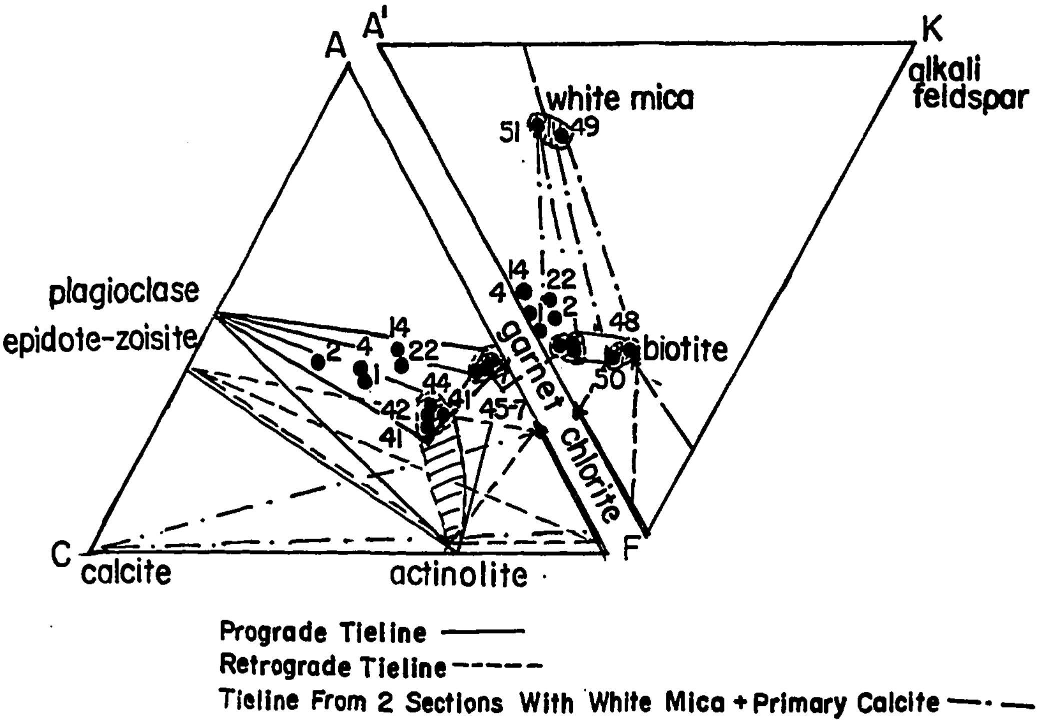


Figure 12. ACF-A'KF and AFM projections of 47 pelitic and quartzofeldspathic schists, pCs and pCf units, Kantishna Hills; major oxide plots derived from table 1.



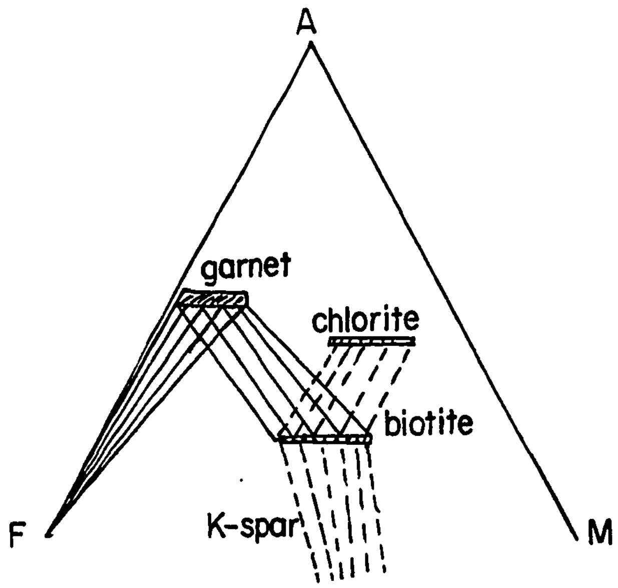


Figure 13. ACF-A'KF and AFM projections of 25 garnet amphibolite and greenschist samples, pCg unit; major oxide plots derived from table 1.

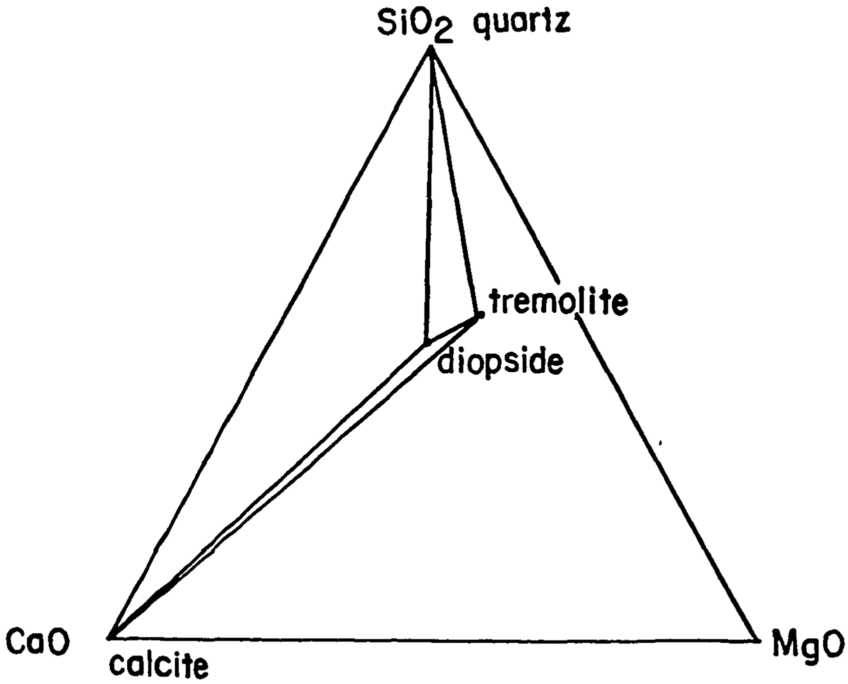


Figure 14. SiO_2-CaO-MgO projection of calcareous rocks, pCm and pCcs units, Birch Creek Schist.

of the study area. It was not possible to distinguish between prograde and retrograde mineral assemblages in calcareous rocks.

Physical measurements of the unit cell edge, refractive index and specific gravity of garnet concentrates from 10 sample sites in the Birch Creek Schist (table 3) enables compositional estimates for five major end members, based on methods described by Deer, Howie, and Zussman (1966, p. 27-28). It is emphasized that these should be considered only approximate compositional estimates because of possible changes in composition caused by retrograde metamorphism, strain deformation, and mineralogical inclusions. However, three of the garnet compositions measured by the Deer, Howie, and Zussman (1966) method were run for major oxide analysis (table 1). The actual oxide values compare well (± 10%) with the values theoretically obtained by the former method (fig. 15a). These results show that the garnet of the prograde mineral assemblage with one exception is dominantly almandine in composition. Thus the prograde mineral assemblage for the northwestern part of the Birch Creek Schist in the study area is best described as the almandine-amphibolite metamorphic facies.

The ubiquitous presence of albite + white mica + biotite + zoisite + chlorite in rocks of basic and pelitic compositions with the added presence of alkali feldspar in the pelitic and quartzo-feldspathic rocks establishes the retrograde event as the lower(?) greenschist facies of regional metamorphism (Turner, 1968).

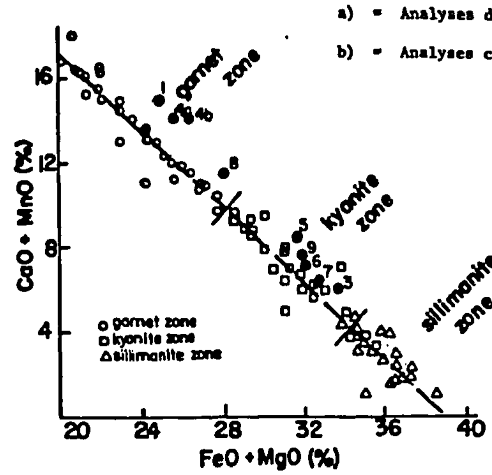
In addition to index mineralogy, textural and structural evidence also supports the contention that two or more periods of recrystallization have taken place. Plagioclase and quartz usually show strain fea-

76BT171	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3[1]	MnO
(a)	35.10	19.71	5.12	1.16	37.34	0.48
(b)	37.34	19.14	5.87	3.28	34.28	0.43
75Ast5 (a)	38.48	18.46	6.01	1.09	32.65	0.80
(b)	37.64	19.08	6.53	4.20	32.32	1.23
76BT273(a)	34.17	19.71	6.83	0.89	34.80	1.91
(b)	37.20	19.63	7.34	1.88	33.20	1.74

[1]Total iron

a) = Analyses derived from Table 1

b) = Analyses calculated from Table 3



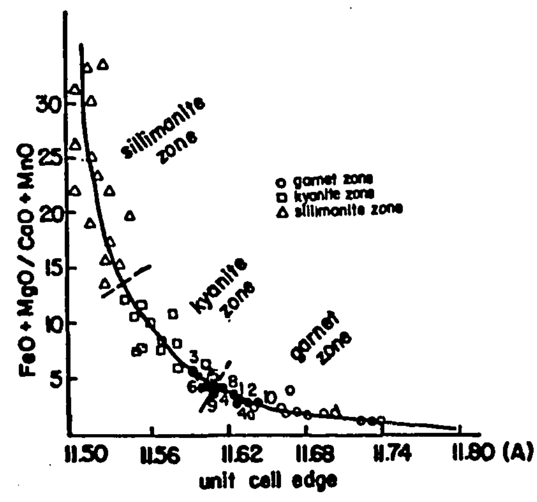


Figure 15a-c. (a) Plot comparing values derived from method described by Deer, Howie and Zussman (1966) with major oxide analyses of garnets from table 1. (b) CaO+MnO-FeO+MgO variation diagram for garnets of differing metamorphic grade showing plots of Kantishna garnet compositions after Nandi (1967). (c) Variation of FeO+MgO/CaO+MnO ratio with the unit cell edge for garnets of varying metamorphic grade; Kantishna garnets after Nandi (1967).

tures and opaque inclusion lines oblique to present schistosity, and some micaceous schists have well developed cleavage (S_2) overprinting former (S_1) schistocity. Garnet and plagioclase porphyroblasts have been 'rolled' and mineral replacements have been deformed into 'S' shaped configurations probably indicating synkinematic metamorphism and folding (fig. 7a). In amphibolitic greenstone (pCg) on Wickersham Dome, relict hornblendes have been deformed and altered whereas secondary unaltered actinolite grains are parallel to schistocity. Structural evidence indicating three distinctive periods of folding in the Birch Creek Schist also suggests a polymetamorphic history.

An apparent gradual increase in metamorphic grade of the prograde event occurs from southeast to northwest in the Birch Creek Schist of the study area. To the northwest Birch Creek Schist units show a prograde almandine-amphibolite facies and retrograde lower(?) greenschist facies, typified by mineral assemblage types (1) and (2) for pelitic and quartzo-feldspathic rocks, type (1) for basic rocks and type (1) for quartzo-feldspathic schist and gneiss shown in table 2. Rock units are coarse grained mica schists, amphibolites, and quartz-feldspar schists and gneisses that contain large rolled garnet porphyroblasts, secondary strain features, and inclusion lines.

The Birch Creek Schist in the southeastern portion of the study area also shows evidence of prograde and retrograde metamorphic events, but the prograde assemblages lack either garnet or hornblende and calcic plagioclase as illustrated by mineral assemblages of type (3) for both basic and pelitic rocks in table 2. Prograding biotite, garnet, and hornblende isograds are shown on plate 2. The appearance of oligoclase in the field area could not be accurately plotted, but is believed to come in at about the same position as hornblende. The boundary between the upper greenschist and almandine amphibolite facies of the prograde event is believed to approximately coincide with the hornblende isograd. Rock units to the southeast are fine grained mica schists, quartzite and amphibolite. Garnet porphyroblasts, where present, are smaller than their counterparts to the northwest. In general, the megascopic size of garnet porphyroblasts, mica, and feldspar grains in all Birch Creek Schist units increases gradually from southeast to northwest. Additionally, a gradual textural evolution from flaser fabric transposed to partially completed recrystallization to complete recrystallization of mineral species progresses in Birch Creek Schist lithologies from southeast to northwest.

The unit cell edge of measured garnets from the Crooked Creek area (tab. 3; pl. 2) gradually decreases to the northwest, consistent with Nandi (1967), who suggests that unit cell edges of garnet decrease progressively with increasing metamorphic grade; he suggests that the garnet unit cell edge is, in itself, a good index of regional metamorphism because larger cations such as calcium and manganese are substituted for the smaller iron and magnesium components during progressive regional metamorphism. A plot of CaO + MnO versus FeO + MgO (figure 15b) shows that four garnets plot in the garnet zone of metamorphism and five in the Crooked Creek area plot well within the kyanite zone of metamorphism as defined by Nandi (1967). A plot of the unit cell edge versus a FeO + MgO/CaO + MnO (fig. 15c) shows that seven of 10 garnets plot in the garnet zone of metamorphism while three in the northwestern most sampled area plot in the kyanite zone of metamorphism. The retrogressive cycle of regional metamorphism throughout the entire Birch Creek Schist complex in the Kantishna area is apparently of uniform grade.

The puzzling absence of the alumino-silicate minerals kyanite, sillmanite, or andalusite in the prograde almandine amphibolite facies metamorphic event of the study area can be attributed to Al_2O_3 deficiencies in the protoliths. Eight of nine analyzed samples of Birch Creek Schist pelitic and quartzo-feldspathic schist (table 1) average 13.4% Al_2O_3, about 2.20% lower than the average pelitic shale reported by Pettijohn (1957, p. 344). The samples reported here compare better with those of sub-graywackes, arkose, or metafelsite which average 11.50, 13.15, and 12.8% respectively (Pettijohn, 1957). Similarly, Evans (1964) and Crawford (1966) attribute the absence of aluminosilicate mineralogy in amphibolite facies rocks of the Otago Schist in New Zealand to an alumina deficient quartzo-feldspathic rich protolith. They also report the presence of co-existing albite and oligoclase within the almandine isograd, a feature observed by the author in Birch Creek Schist units of the Kantishna Hills.

Turner (1968, p. 307) and Banno (1964) have drawn attention to the significance of the order of appearance of index minerals in different metamorphic terranes. They conclude that the early appearance of almandine is indicative of high metamorphic pressures. The order of appearance of index minerals as observed in the Kantishna study area (pl. 2) best compares to that of East Otago, New Zealand and the Dalradian Series of Scotland (fig. 16) which are belts of relatively high pressure regional metamorphic facies.

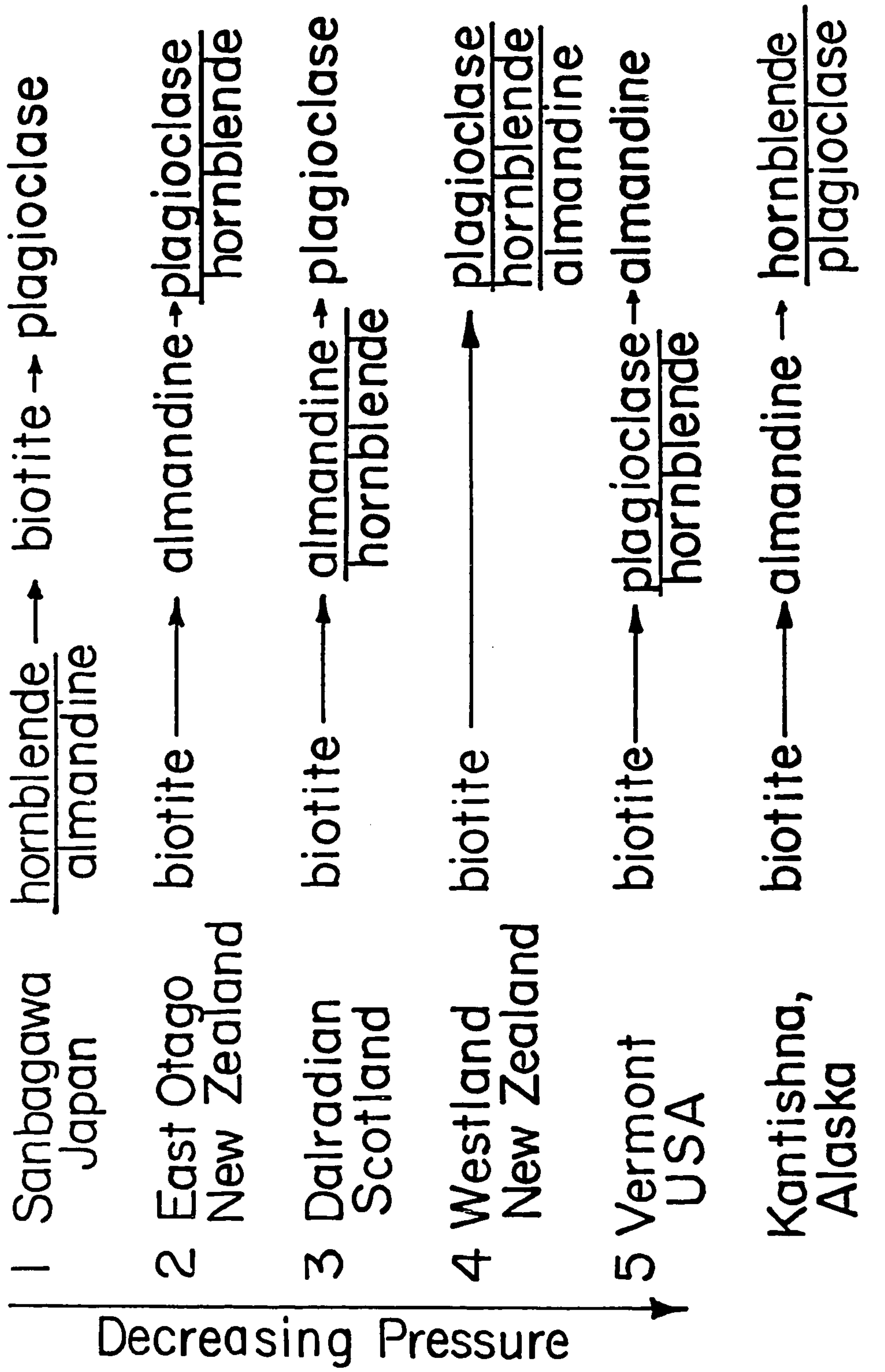


Figure 16. Comparison of relative order of appearance for metamorphic index minerals of Birch Creek Schist prograde event with five well known metamorphic belts from Turner (1968, p. 307).

The Birch Creek Schist to the east in the Wyoming Hills exhibits metamorphic features similar to those in the southeastern portion of the study area (Gilbert and Redman, 1977, p. 3). Wahrhaftig (1968) mapped Birch Creek Schist in the central Healy quadrangle in the greenschist facies of regional metamorphism. These authors do not describe garnet as a mineralogical constituent of the Birch Creek Schist in their respective study areas. Thus, the apparent differences in metamorphic grade from southeast to northwest may indicate differing structural levels within the Birch Creek schist in the Kantishna Hills with deeper levels to the northwest.

Age

Assigning an age to the Birch Creek Schist in the study area is problematic because 1) it is tectonically juxtaposed against younger metamorphic sequences, 2) K-Ar age dating has only been able to date pre-Jurassic (< 195 m.y.) metamorphism and 3) no fossils have been found.

Bundtzen and Turner (1979) have reported hornblende and mica ages from polymetamorphic rocks from the Birch Creek Schist in the study area (pl. 1). Four mica separates from two samples of biotite-garnet-quartz-feldspar schist (pCs unit) yield ^{40}K-^{40}Ar ages ranging from 100.2 to 85.7 million years. Muscovite ages are concordant and significantly older (x = 100.0 m.y.) than the biotite ages (x = 89.7 m.y.). Four hornblende separates from garnet amphibolite (pCg) yield ages ranging from 195.4 to 104.0 m.y. The observed order of apparent argon retention in the dated minerals (hornblende > muscovite > biotite) is identical with that generally observed for these minerals (Dalrymple and Lanphere, 1969). These data are believed to represent varying amounts of radiogenic-argon loss from an older pre-Jurassic metamorphic event(s) during a mid-to Late Cretaceous thermal event. This is consistent with petrographic evidence reported here which has shown that a retrograde greenschist facies event has overprinted a prograde upper greenschist-to-amphibolite facies metamorphism. The oldest amphibole age of 195.4 m.y. thus represents a minimum age for the Birch Creek Schist in the study area; the mica ages could represent either the lower greenschist facies retrograde event or cooling ages caused by uplift and removal of overburden. Mica and amphibole ages in the polymetamorphic basement of the Big Delta Quadrangle in the Yukon-Tanana Upland (Foster and others, 1979) have similar age patterns to those reported by Bundtzen and Turner (1979), suggesting both areas underwent similar thermal histories.

Florence Weber (USGS, oral commun.) has informally classified porphyroclastic quartzite in the Yukon-Tanana Upland similar to those found in the pCs unit in the Kantishna Hills as the 'Wickersham Grit' after exposures on Wickersham Dome north of Fairbanks. She believes that these distinctive quartzose rocks are correlative with the 'Windermere Grit' of the northern Cordillera, which is regarded as Late Precambrian in age. The Birch Creek Schist in the study area has undergone at least one more cycle of regional metamorphism than the overlying Keevy Peak Formation and Totatlanika Schist which are considered early to mid-Paleozoic age (Gilbert and Bundtzen, 1979). Thus the author tentatively assigns the Birch Creek Schist of the Kantishna region a Precambrian age as did previous workers, although portions of it could be somewhat younger.

Spruce Creek Sequence

Introduction

A narrow band of dark gray slate and phyllite, greenish gray chloritic phyllite and semischist, light tan metafelsite, quartzo-feldspathic phyllite, and medium gray micaceous marble, herein named the 'Spruce Creek Sequence,' after exposures near the head of Spruce Creek (fig. 17) crops out continuously in a northeasterly direction from Eldorado Creek to Canyon Creek (pl. 1). The apparent thickness of this sequence ranges from 500-to-1,000 meters, but it is complexly deformed, and could be structurally repeated.

Wells (1933, p. 345) first mapped a conspicuous belt of "limestone and chlorite schist" as a distinctive portion of the metamorphic rock section in the Kantishna mining area. Morrison (1964, pl. 1) has shown these rocks as diapthoritic gneiss, marble, and calcareous magnesium schists that crop out in a discontinuous belt enveloped in pelitic quartz mica schist. Both workers believed that these lithologies were conformable with and part of the Birch Creek Schist.

During this study, the Spruce Creek Sequence was mapped as two distinctive units: 1) metafelsite, quartzo-feldspathic gneiss, and chlorite rich phyllite and semischist (Psf) and 2) graphitic phyllite, semischist, and marble (Psg). These rocks were informally referred to in the field as "the ore zone rocks", because many quartz-carbonate-sulfide veins in the Kantishna mining district (described later) are hosted in them. The Spruce Creek Sequence is believed to be generally in tectonic contact with Birch Creek Schist units, although a possible conformable contact re-

Figure 17. Light-toned metafelsite (Psf) and darker graphitic phyllite and marble (Psg) of Spruce Creek Sequence near the head of Spruce Creek.

lationship exists east of Myrtle Creek where, the former overlies the latter (pl. 1).

Graphitic phyllite, semischist, and marble (Psg)

Distinctive bands of dark gray, fine grained, micaceous marble and medium-to-dark gray graphitic phyllite and semischist are exposed in nonresistant outcrops in the southern Kantishna Hills. These rocks form distinctive dark gray outcrops and rubble on hillsides in contrast to interbedded, light tannish gray-to-green rocks of the Psf unit (described later) and silvery-gray, muscovite and quartz rich units of the Birch Creek Schist. Macroscopic folds, kink bands and secondary cleavage are common structural features observed in outcrop. The marble displays distinctive hackly pitted weathering while graphitic phyllite and semischist tend to exhibit more friable slaty cleavage. Minor amounts of dark gray slate are found with the phyllitic units. In the marble, quartz-white mica lamina form resistant rims that protrude from the chemically weathered carbonate layers. Some of the graphitic units on Eldorado Creek and near the headwaters of Caribou Creek contain pyrite megacrysts up to 1 cm in diameter that may make up to 15% of a given outcrop.

In thin section, the marble varies from almost pure carbonate (mainly calcite) to impure varieties that contain 85-90% interlocking calcite grains 0.5 mm long, and scattered quartz, white mica, alkali feldspar, albite, chlorite, and graphite grains. Impure marble is normally banded with essentially pure 1 cm thick calcite laminations alternating with calcite rich layers of equal thickness containing up to 25% graphite, chlorite and white mica quartz botryoids; isolated quartz grains occur in both layers. Random rounded dolomite concretions up to 1 cm in diameter occur locally and appear as orange spots and splotches on a dark gray fine grained background. Both varieties of marble are intruded by secondary, light gray, bleached, calcite veins several centimeters thick.

Graphitic phyllite and semischist are composed of about 45% quartz and 55% graphite + white mica + chlorite ± biotite± zoisite/clinozoisite and albite. Many varieties of phyllite concentrate mafic and felsic minerals in leucocratic layers that range from 0.5 mm to 5 mm thick. Some of the Psg unit exposed in Spruce Creek and Eldorado Creek canyon is composed of dark gray, graphite-bearing, porphyroblastic, quartzose phyllites. Thin sections show porphyroblasts of sub-to euhedral albite (An 5-11) in a ground mass of interlocking quartz (80%) and feldspar (10%). Zoisite and/or clinozoisite + biotite + graphite + white mica and chlorite may make up to 20% of a speciman; this gives the rock its medium to dark greenish-gray color.

Metafelsite, quartzofeldspathic gneiss, and chloritic phyllite and semischist (Psf)

Tan weathered, light gray, blastoporphyritic, subschistose metafelsite, bleached quartzo-feldspathic gneiss, and medium-to-dark green, chloritic phyllite and semischist form the Psf unit which is interbedded and associated with the Psg unit. Psf and Psg units laterally grade into one another. About 60% of the Psf unit is composed of quartzo-feldspathic gneiss and blastoporphyritic metafelsite. Although not all thin sections show conclusive evidence of a meta-igneous origin, samples collected from the Glenn Creek-Spruce Creek area, from the headwaters of Twenty-two Gulch, and Quigley Ridge contain relict igneous textures. In thin section, these rocks contain relict euhedral, nondirectional relict albite phenocrysts(?) up to 1 cm in length that display albite, carlsbad, and baveno twinning in a groundmass of very fine grained quartz + white mica + chlorite + undetermined feldspar and sphene. The relict albite phenocrysts are sometimes bent and usually have ragged borders (fig. 18). Subangular to rounded quartz grains up to 5 mm in diameter show strong embayed contacts that are interpreted as resorption textures (fig. 19). The quartz and plagioclase grains can comprise 30% of a speciman but the average is about 15%. Fine grained white mica is found as distinctive stringers parallel to mineralogical orientation in the groundmass and as flecks in the albite grains. Veins of carbonate and opaques 5 mm wide cut altered samples. Most specimans have a subschistose texture but some are nearly massive metafelsites difficult to distinguish from unmetamorphosed, felsic volcanic rocks. The lenticular nature of outcrop patterns, parallalism to compositional banding of adjacent units, and blastoporphyritic texture suggest that the metafelsites are relict extrusive rather than intrusive rocks. In addition to mineralogical and textural evidence, whole rock chemical analyses (table 2) also suggest a meta-igneous parentage for these rocks. An A-F-M plot (fig. 10) and examination of Na_2O and K_2O content show that they probably represent a calc-alkaline volcanic suite (Carmichael, and others, 1974).

Some of the Psf unit is composed of quartz rich, micaceous quartzofeldspathic semischist and gneiss with a more distinctive banded or foliated texture than metafelsites previously described. Mineralogical compositions include white mica + quartz + plagioclase (albite) ± calcite + clinozoisite/zoisite + quartz + phlogophite + alkali feldspar. Porphyroblasts of carlsbad twinned albite and anhedral elliptical quartz

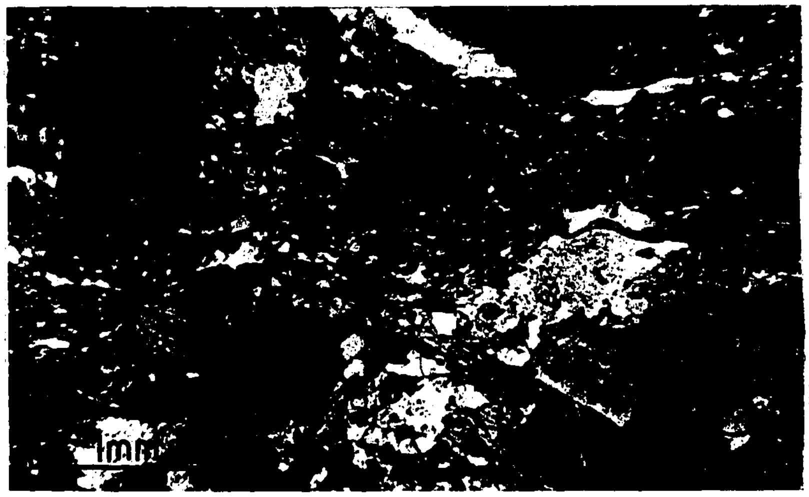


Figure 18. Photomicrograph of metafelsite Psf unit. Note euhedral shaped (a) albite grains oblique to fabric and (k) alkali feldspar. Groundmass composed of quartz, feldspar, and fine grained white mica (crossed nicols; 75Ast1881).

Figure 19. Photomicrograph of metafelsite, Psf unit. Note resorption channel in quartz grain (q) and albite-carlsbad-baveno-twinned (a) albite grain (crossed nicols; 75Ast1973).

achieve maximum dimensions of 5 mm. Interlocking white mica, quartz and feldspar anhedra are oriented along foliation planes. These varieties are believed to be metamorphosed tuffs possibly equivalent to more massive meta-igneous flow(?) rocks described previously.

Medium to dark green, amphibole bearing, chlorite-rich phyllite and semischist form nonresistant rubble in depressions and saddles in contrast to the more resistant interbedded quartz rich meta-igneous felsites and quartzo-feldspathic gneiss previously described. Mineralogical compositions include: chlorite + green biotite + zoisite and/or clinozoisite + albite ± tourmaline + quartz ± graphite. Most thin sections contain at least 50% chlorite group minerals and 5-10% idioblastic actinolite grains. Some specimans have up to 40% epidote group minerals (usually clinozoisite) concentrated within mica rich horizons. Light brown-green, equant, idioblastic actinolite porphyroblasts up to 1 cm in diameter show twinning parallel to the 100 twin plane; these megacrysts are either unaltered or jacketed in penninite or opaque minerals. Distinctive light- to dark-green, strongly pleochroic biotite forms isolated elongated grains in the groundmass; tourmaline is usually present in minor (< 2%) amounts. Most of the chlorite group minerals, feldspar and quartz show a preferred orientation parallel to schistocity defining foliation measured in outcrop. Graphite, where present, occurs as small anhedral rods and masses within the groundmass, locally making up about 5% of the rock. Almost all thin sections show secondary deformation oblique to foliation in the form of crenulations, kink bands and secondary cleavage. Chloritic phyllite and semischists of the Psf unit are difficult to distinguish in the field from greenschists of the pCg unit of the Birch

Creek Schist except for several significant differences: 1) Psf 'greenschists' do not show mineralogical assemblages in disequilibrium characteristic of pCg units, 2) garnets are absent in Psf greenschists while common in pCg chlorite rich units and 3) Psf units tend to be finer grained than similar pCg units; hence the textural terms 'phyllite' and 'semischist' for the former lithology.

Metamorphic history and age

Rocks of the Spruce Creek Sequence have mineralogical compositions typical of low-grade metamorphism. The mineral assemblage chlorite + zoisite/clinozoisite + actinolite + biotite + quartz, which can be found in all Spruce Creek Sequence units, defines the biotite zone of the greenschist facies of metamorphism (Winkler, 1967). No mineral assemblages in disequilibrium were recognized. Chemical compositions of Spruce Creek Sequence quartzo-feldspathic and basic rocks are similar to those described for respective units of the Birch Creek Schist (table 2 and fig. 10). Structural and petrographic evidence show that two dynamic metamorphic events occurred during regional thermal events that both reached the greenschist facies. ACF-A'KF, projections representative of Spruce Creek Sequence lithologies are shown in figures 20-21; table 4 summarizes the mineral assemblages.

Morrison (1964, p. 37-38, and pl. 1) describes relict oligoclase (An_{25}, An_{26}) and garnet in his diapthoritic gneiss units on Quigley Ridge and at the head of Rainy Creek--mineralogy typical of higher grade metamorphism in the Birch Creek Schist. The diapthoritic gneiss has been mapped as part of the Spruce Creek Sequence in this report. The author found no garnets in any of the rocks shown on plate 1 as the Spruce

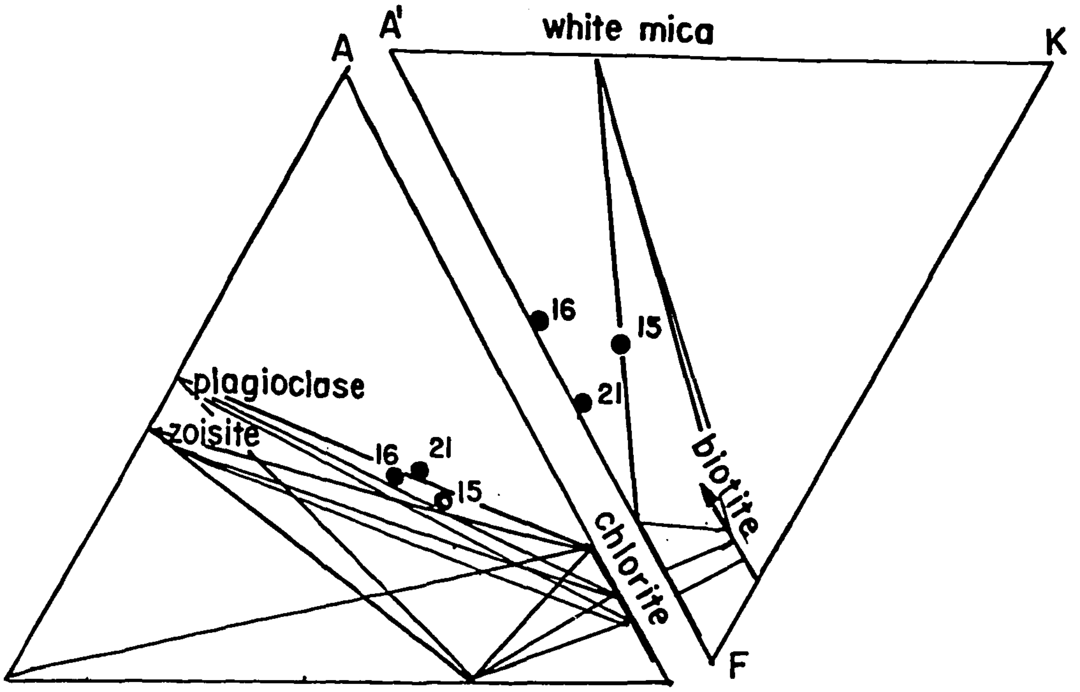


Figure 20. ACF-A'KF projections of nine basic rocks of Spruce Creek Sequence; major oxide plots from Table 1.

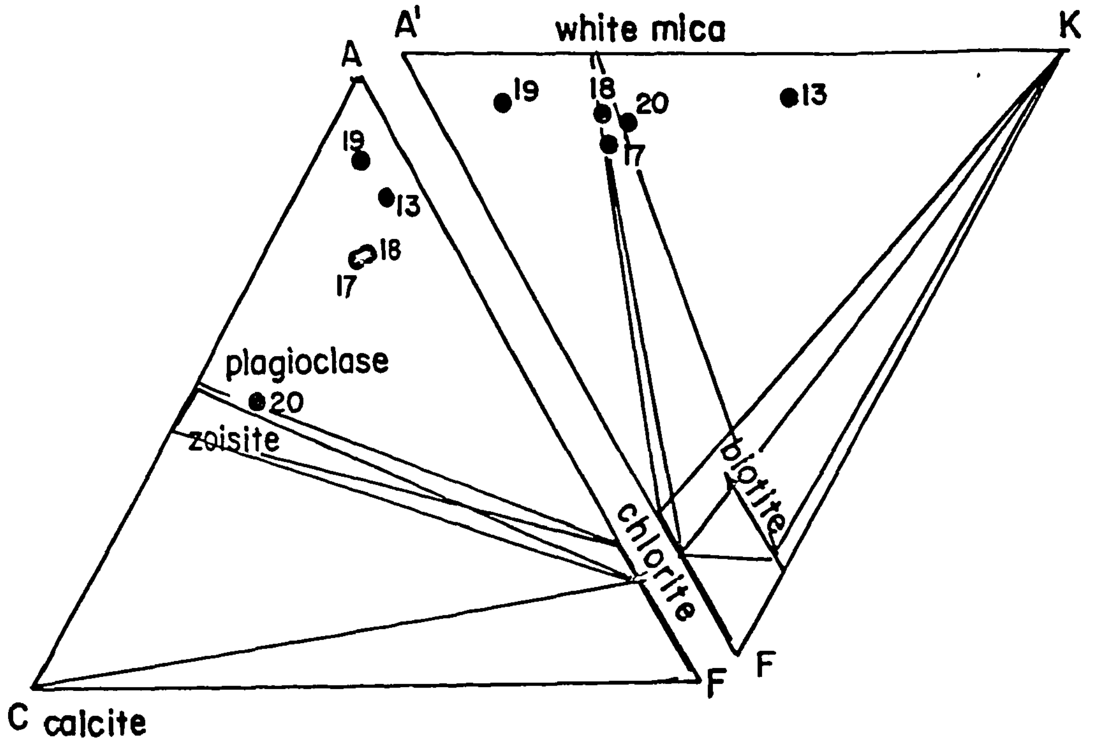


Figure 21. ACF-A'KF projections of 37 quartzofeldspathic phyllite and pelitic rocks, Spruce Creek Sequence; major oxide plots from table 1.

Creek Sequence. Small, unmappable units of Birch Creek Schist are believed to be tectonically intercalated with the Spruce Creek Sequence near Quigley Ridge and near Spruce Creek. If Morrison (1964) is correct, then 1) his samples were derived from tectonically emplaced lenses of Birch Creek Schist within the Spruce Creek Sequence. 2) higher grade metamorphic mineral assembledges than those reported here exist in these rocks or 3) he sampled rocks mapped as diapthoritic gneiss outside the areas mapped here as Spruce Creek Sequence (pl. 1). A combination of 1) and 3) could account for the disparity.

If the author's conclusions are correct, then the Spruce Creek Sequence sharply contrasts in both metamorphic grade and history with the Birch Creek Schist. Field evidence strongly suggests that the Spruce Creek Sequence is in fault contact with the Birch Creek Schist due south of Wickersham Dome, in the valley of Glenn Creek, west of Yellow Creek and at the headwaters of Crevice Creek, where prominant shear zones and structural discordance exist. However, contacts between the two formations appear superficially conformable east of Myrtle Creek with the latter overlying the former. Because of tectonic contacts in key areas and disparity in metamorphism, the Spruce Creek Sequence is believed to be thrust over the Birch Creek Schist on Eldorado Creek, on Wickersham Dome, south of the Spruce Creek-Glenn Creek divide and on the north flank of Kankone Peak.

No fossils have been found in the Spruce Creek Sequence. R. B. Blodgett of Oregon State University dissolved Spruce Creek Sequence carbonate samples submitted by the author from four localities in the study area, but failed to find conodonts or other fauna. These rocks bear some resemblance to the Keevy Peak Formation, and Totatlanika Schist first described by Wahrhaftig (1968) in the central Alaska Range. Major oxide analyses (table 1, fig. 10) of meta-igneous rocks from the Totatlanika Schist of Mississippian age and Spruce Creek Sequence are remarkably similar; however, the gross lithologic packages of each sequence significantly differs. The author notes similarities of Spruce Creek Sequence lithologies with the Delta Mineral Belt, of the Eastern Alaska Range, which host stratiform massive sulfide deposits (Nauman, 1980). Both the Spruce Creek Sequence and Keevy Peak Formation contain abundant graphite rich units, scattered metafelsite and marble lenses, and have similar metamorphic histories. However, metaconglomerates, black quartzite, and metasandstone typical of the Keevy Peak Formation are absent in the Spruce Creek Sequence while the thick section of chloritic units and metafelsite described here (Psf unit) is not typical of Keevy Peak Formation in other parts of the Kantishna Hills or in the central Alaska Range. In addition, the Spruce Creek Sequence appears to be more dynamically deformed and regionally metamorphosed than the Keevy Peak Formation to the east of the study area. Thus, the author tentatively assigns the Spruce Creek Sequence an Early Paleozoic age.

Keevy Peak Formation

Introduction

Wahrhaftig (1968, E11-12) described a belt of quartz-sericite schist, black carbonaceous schist, gray and purple slate, black quartzite, and stretched pebble conglomerate as the Keevy Peak Formation, after exposures on the northwest shoulder of Keevy Peak in the Healy D-3 Quadrangle about 100 km east of the study area. More recent workers such as Gilbert (1977), Gilbert and Bundtzen (1976), Gilbert and Redman (1977), and Gilbert and Bundtzen (1979) have correlated rock units in the north-central Alaska Range both east and west of Wahrhaftig's (1968) study area with the Keevy Peak Formation. Rocks essentially identical in composition, character and stratigraphic position to Wahrhaftig's Keevy Peak Formation have been mapped in two northeasterly belts in the northern part of the study area and near Canyon Creek in the east-central portion of the study area. Bundtzen, Smith, and Tosdal (1976) originally considered the Keevy Peak Formation in the Kantishna Hills as subunits of the Totatlanika Schist. In the type area Wahrhaftig (1968) shows the Keevy Peak Formation unconformably overlying the Birch Creek Schist and overlain conformably by the Totatlanika Schist. In the Kantishna Hills, the Keevy Peak Formation is believed to be everywhere in tectonic contact with the Birch Creek Schist. It may be conformably overlain by the Totatlanika Schist.

Folding, faulting and other structural complexities make thickness estimates of the Keevy Peak Formation tenuous, but the least disturbed and most complete section is exposed at the head of the south fork of Chitsia Creek. There, between the faulted contact with the Birch Creek Schist and the conformable(?) contact with the Totatlanika Schist, the Keevy Peak Formation is estimated to be approximately 1,500 meters thick. In the Chitsia Mountain section (fig. 22) the basal unit consists of about 300 meters of calcareous schists and phyllites which is overlain by over 1,000 meters dark gray slates, limestone and black quartzites. Unmappable lenses of stretched pebble conglomerates are found near the top of the section.

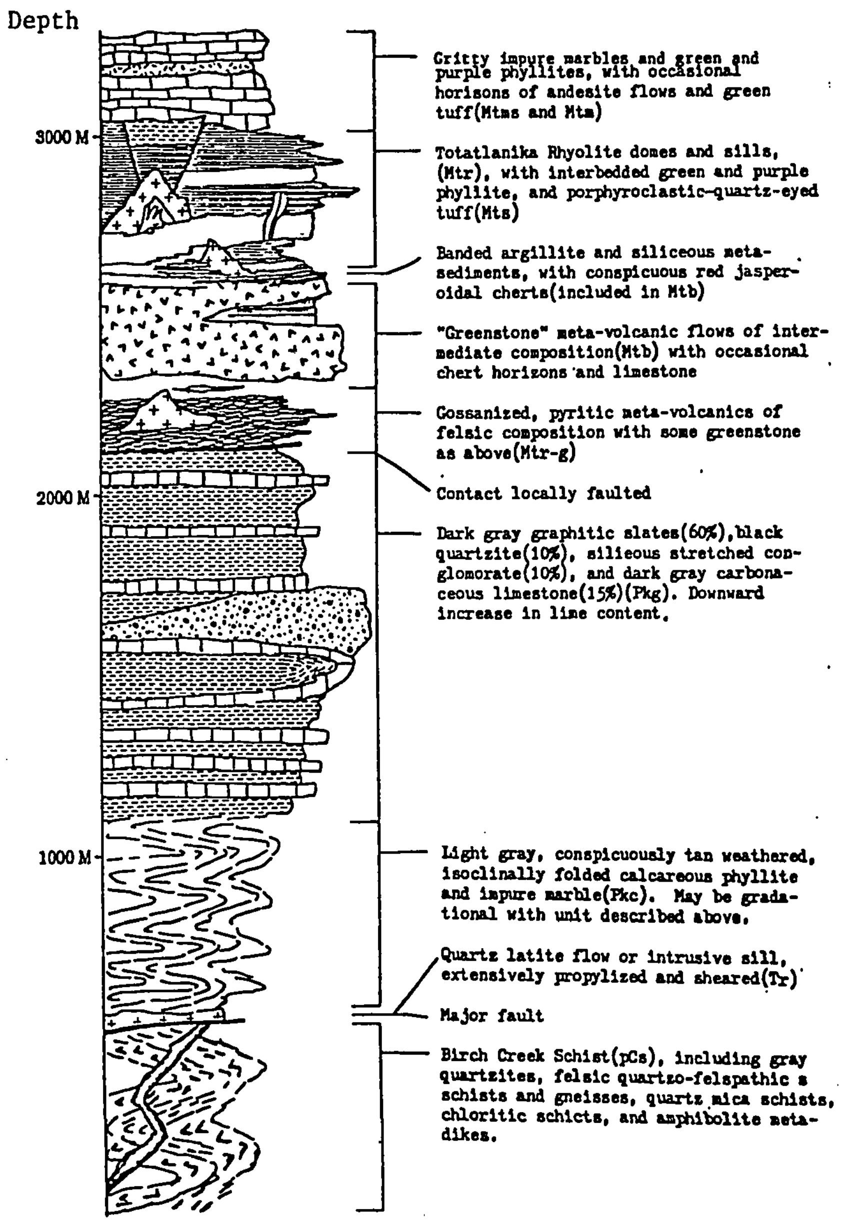


Figure 22. Composite stratigraphic section of metamorphic rocks in Chitsia Mountain area.

The Keevy Peak Formation in the study area has been mapped as calcareous semichist and phyllite (Pks), black quartzite, slate and marble (Pkq) and metaconglomerate (Pkc). Much of the parent material of the Keevy Peak Formation was probably organic rich chert, sandstone, conglomerate and siltstone that was formed in a deep water marine, low energy environment as suggested by Gilbert and Bundtzen (1979); however, the prograding coarsening upward sequence of rocks could represent submarine fan deposits on an adjacent submarine slope.

Calcareous semischist and phyllite (Pks)

The basal portion of the Keevy Peak section near Chitsia Creek is composed of light gray, conspicuously tan weathered , micaceous, calcareous semi-schist, minor muscovite rich marble, and graphitic phyllite. This unit is coarser grained and more deformed than the overlying Pkg unit. A secondary cleavege (S_2) oblique to compositional banding (S_1) obscures structural relationships with other units. Numerous quartz-calcite veins up to 1 m thick stand out in relief as resistant lumps against the non-resistant, platy-fissle micaceous layers in the phyllite and semischist. A distinctive silvery gray, mica sheen, not unlike that observed in Birch Creek Schist units, is exhibited in some outcrops. The Pks unit imperceptively grades from a muscovite calcareous-rich unit at the base of the section to graphite-rich lithologies near the top. The contact with the overlying Pkg unit is gradational and approximately shown on plate 1.

In thin section micaceous marbles are composed of very fine-grained laminations up to 1 cm thick of 95% calcite, 2-3% muscovite and 2% thin graphite rods and masses--all grains show preferred orientation parallel foliation. Scattered quartz grain are distributed in the groundmass. The laminated nature of these rocks is believed to represent relict sedimentary layers of alternating carbonate and mud.

Graphitic phyllite and semi-schist contain approximately 45% graphite, 40% quartz, 10% undetermined opaques (pyrite?) and 5% chlorite, muscovite and epidote (as very samll grains). Graphite orientation and interbedded relationships with calcareous units define S_1 foliation.

<u>Black quartzite, slate, and marble (Pkq)</u>

The thickest and most aerially extensive unit of the Keevy Peak Formation in the study area is the Pkq unit, informally referred to as the 'black quartzite' in the field because of the presence of conspicuous dark-gray, laminated-to-massive quartzite. The Pkq unit is exposed in three main belts: (1) as an almost continuous belt of rocks of unknown thickness extending 35 km from the headwaters of Little Caribou Creek northeastward to the northern limit of the Kantishna Hills east of the Toklat River, (2) as a 1,000 meter thick section overlying the Pks unit on Chitsia Creek, and (3) as a 300 meter thick section trending about 10 km from Moonlight Creek northeastward to Stampede Creek.

About 60% of the Pkq unit is composed of dark gray, limonitically stained, carbonaceous slate sometimes grading into phyllite. These rocks are commonly crenulated and some outcrops show a well developed, secondary cleavage oblique to compositional banding. Quartz-carbonate ± pyrite veins intruding along joints and fractures comprise up to 20% of a given outcrop area. Fine grained pyrite laminations of few millimeters thick are locally abundant in exposures on Chitsia and Moonlight Creeks and are probably responsible, in part, for the limonitic staining seen in this unit.

In thin section these rocks are composed of about 60% amorphous masses of graphite and 35% interocking quartz grains. Traces of sericite, undetermined feldspar, white mica and chlorite occur as thin wisps parallel to foliation. Flaser shaped quartz and graphite rods are common textural features found in these rocks.

Interbedded with the carbonaceous slate and phyllite are dark gray, very fine grained, laminated and massive quartzite, medium gray, medium grained marble beds and minor green porphyroclastic quartz bearing phyllite. The thinly laminated variety earned the black quartzite the field term 'zebra quartzite' due to striking alternations of dark gray and light gray layers. The quartzite forms very resistant knobs and ridges in contrast to nonresistant marble and grphite rich units, a factor that can lead to an overestimation of its relative volume in the rock section.

The 'zebra quartzite' is composed of 90% very fined grained quartz anhedra and about 10% graphite. The alternating light gray and very dark gray layers, usually less than 1 cm thick observed in hand specimen, are due to relative graphite versus quartz content at a ratio of 1:1. In some localities, this layering is remarkably continuous and uniform along the strike for several meters of outcrop. Small amplitude (5 mm) wavy fold structures observed in outcrop do not lense out, but rather, are offset by small microfaults.

Dark gray, unbanded, very fine grained, massive quartzite is composed of about 95% interlocking quartz anhedra and 5% graphite; the graphite interstitial to the quartz grains causes the gray color in hand specimen. The quartzites commonly exhibit brittle deformation in the form of brecciation especially on the hills immediately south of Crooked Creek. Both varieties of quartzite are believed to be recrystallized cherts with laminations in the 'zebra quartzite' representing alternating deposits of silica and carbon rich organic(?) material in a low energy, deep water marine environment. In one sample of massive black quartzite near Crooked Creek, rounded organic(?) clear features seen in plain light could be recrystallized radiolaria.

Brownish gray, medium to fine grained, lithic rich metasandstones are interbedded with the dark gray slates and marble near Marten, Crooked and Canyon Creeks. These rocks are composed of angular clasts of slate, quartz, chert, undetermined feldspar, flecks of white mica and opaques in a 'dirty' groundmass of opaques and quartz. Some outcrops appear to be almost unmetamorphosed with relict load casts, and graded bedding still recognizable (fig. 23). These metasandstones probably represent relict graywackes in a submarine fan or flysch sequence.

Medium gray marble form mappable lenses up to 1 mile long and 100 meters thick near Stampede and Canyon Creek. Unmappable marble lenses are found throughout the Pkq unit. These are composed largely of pure calcite with traces of sericite and quartz.

Greenish porphyroclastic quartz phyllite is exposed in two isolated lenses on the ridge above the Stampede Mine. These porphyroclastic quartzite layers are not unlike those in the Birch Creek Schist except the Pkq variety is finer grained than the Birch Creek Schist counterpart

Figure 23. Folded metasandstone of Pkq unit, Crooked Creek area (76BT252).

and contains less than 1% white mica along with the 95% quartz occurring both in the fine grained groundmass and as large trimmed quartz eyes.

Metaconglomerate (Pkc)

The most distinctive unit in the Keevy Peak Formation in the study area is composed of light-tan to medium gray, stretched pebble intraformational conglomerate and phyllite that appear as lens shaped wedges a few miles long and several hundred meters thick at the top of the Keevy Peak Formation section. These metaconglomerates form resistant knobs, ridges, and large outcrop masses along cliff faces due to their high quartz content.

The dominant textural feature both megascopically and in thin section is cataclasis, with original sedimentary clasts of chert, undetermined feldspar, slate, and sandstone ranging in size from a few millimeters to several centimeters (rarely up to 25 cm) stretched parallel to bedding and/or foliation with 3 to 4:1 length-to-width ratio (fig. 24). Some of the quartz and chert clasts have been partially recrystallized to amorphous masses of quartz anhedra while clasts of feldspar and sandstone are flecked with sericite and chlorite. In most thin sections, cracks and fractures have formed along clast-groundmass boundaries and have extended into the fine-grained-graphite-quartz groundmass. These cracks are usually filled with limonite and minor sericite; additionally, clasts of slate and phyllite are limonitically altered. Most of the quartz clasts exhibit a biaxial character (2V = 10°) which suggests significant strain deformation. Some of the stretched pebble conglomerates on Marten Hill (pl.1) are chert breccias with cavities filled with sericite, limonite, and secondary quartz.

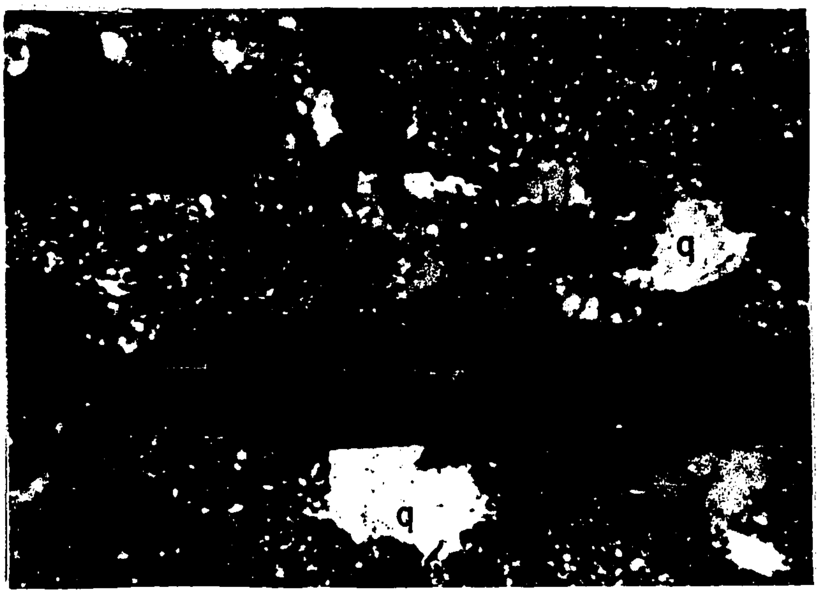


Figure 24. Photomicrograph of stretched-pebble conglomerate, Chitsia Creek area (q) quartz, (g) graphite-rich flaser, (m) quartz rich matrix (crossed nicols; 75Ast2836).

A few varieties of metacongomerate are quartz and silica poor and contain dominantly feldspar, slate, sandstone and phyllite clasts. This type of metaconglomerate is usually finer grained and much less resistant in outcrop than quartz rich varieties previously described.

Metamorphic history and age

The Keevy Peak Formation in the study area has primarily undergone a strong dynamic metamorphism coupled with a low grade thermal event and subsequent fold deformation; many samples are true cataclastites. The initial development of chlorite, white mica and clinozoisite in the basal member (Pks) suggests a lower greenschist facies metamorphism locally, but much of the section has undergone a 'very low grade' metamorphism (Winkler, 1967). No definitive metamorphic mineral assemblages could be identified in either the Pkq or Pkc members probably due to their high quartz content. A summary ACK-AKF' projection and mineral assemblages of the Keevy Peak formation are provided in Figure 25 and Table 4.

No definitive fossils have been found within the Keevy Peak Formation in the study area. Recrystallized radiolaria(?) found near Crooked Creek are not age definitive. R. B. Blodgett dissolved two samples of marble from the Psg unit from the study area in an unsuccessful search for conodonts and other fauna. Gilbert and Redman (1977) have reported Middle to Late Devonian fossils from four localities in rocks correlative with the Keevy Peak Formation in the Wyoming Hills east of the study area. In the Healy D-2 Quandrangle near Wood River, samples collected by John Dunbier (Noranda Co.) of black calcareous schist and marble of

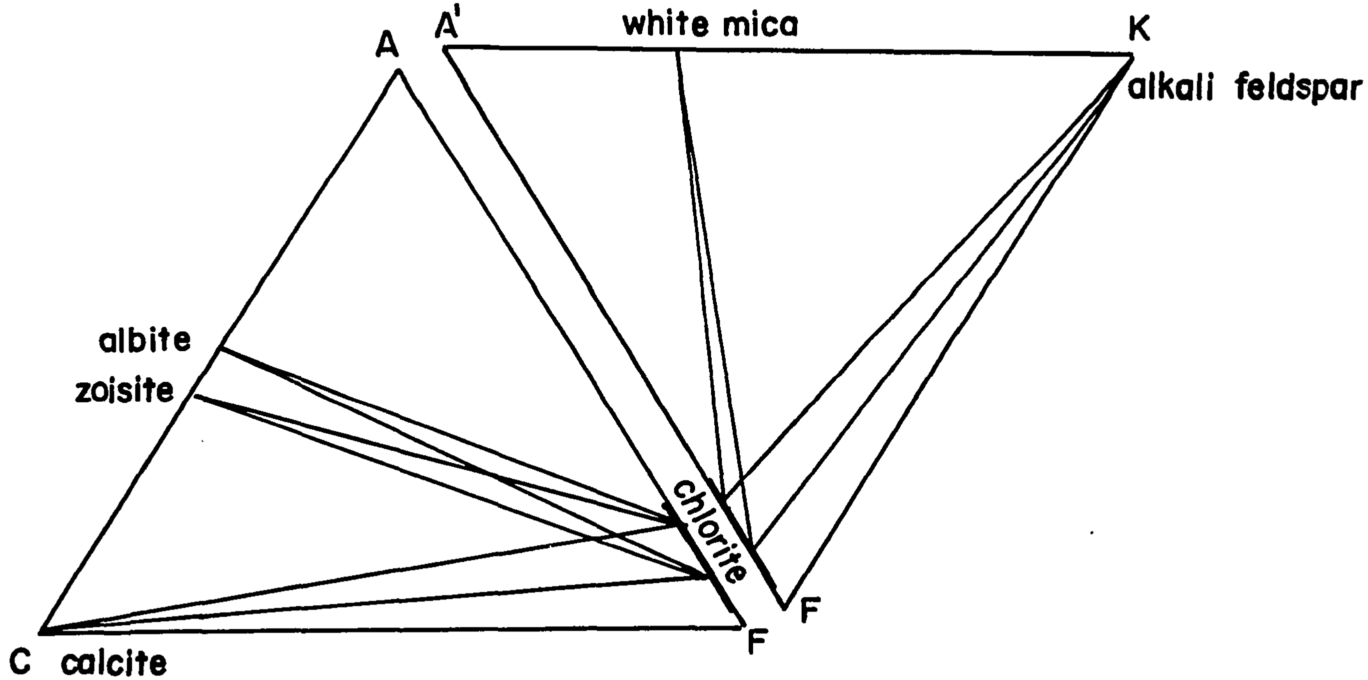


Figure 25. ACF-A'KF projection of pelitic and basic rocks from Keevy Peak Formation.

the Keevy Peak Formation contained poorly preserved fossils of Ordivician-to-Devonian age (Gilbert and Bundtzen, 1979).

The Keevy Peak Formation is everywhere in fault contact with the Birch Creek Schist, but is believed to be conformably overlain and interbedded with the Totatlanika Schist of Upper Devonian-Mississippian age near Crooked and Chitsia Creeks. If these structural interpretations hold true, then the Keevy Peak Formation is probably Middle-to-Late Devonian in age although the basal Pks unit could be older.

Totatlanika Schist

Introduction

Prindle (1907, p. 206-207) and Brooks (1911, p. 149-150) first described a belt of 'porphyritic' quartz-orthoclase-sericite schists and chert in the foothills of the central Alaska Range and provided textural, structural and mineralogical evidence for a meta-igneous origin. Capps (1912, p. 22-23) mapped these same rock units in two belts throughout the Bonnifield mining district and named them the Totatlanika Schist, after "excellent exposures...in the lower canyon of the Totatlanika River." Capps included in his Totatlanika Schist metaconglomerate and quartz-sericite-schist that were later regarded as part of the Keevy Peak Formation (Wahrhaftig, 1968). Capps (1940) first recognized the Totatlanika Schist in the northern Kantishna Hills but mapped the Birch Creek Schist--Totatlanika Schist contact as roughly perpendicular to the one shown on plate 1. His geologic map did not differentiate the Keevy Peak Formation from the Birch Creek Schist.

Ragan and Horlocker (1962) examined outcrops in the Totatlanika River near Capp's (1912) original type section and concluded that the quartz-orthoclase-sericite schists were cataclastites derived from a coarser grained parent by varying degrees of mylonitization. Additionally they suggest that, with the exception of composition, there is no evidence of an igneous parentage and the Totatlanika Schist is of crystalline schist origin, a conclusion that runs contrary to previous work and the ideas presented here.

Wahrhaftig (1968, E1-E2) systematically divided the Totatlanika Schist in his study into distinctive members and described them as follows:

> "(1) At the base is the Moose Creek Member, 0-5,000 feet thick, which consists of three strongly contrasting lithologies--black schist, green chloritic schist, and yellow quartz-orthoclase gneiss and schist, (2) overlying this is the California Creek Member, at least 3,000 feet thick, which consists of white- to buff-weathering gray quartz-orthoclase gneiss and schist, one facies of which contains abundance megacrysts of orthoclase up to 2.5 centimeters long, (3) overlying and interfingering with the California Creek Member is the Chute Creek Member--1,300-1,500 feet of dark-green chloritic schist, (4) this in turn is overlain by the Mystic Creek Member--2,000-3,000 feet of predominantly fine grained purple, green, and yellow schist of rhyolitic origin, and (5) at the top is the Sheep Creek Member consisting of 400 to 1,000 feet of black schist, overlain by 2,000 feet of purple and green slate (probably metamorphosed tuff) overlain by 2,000 feet of epiclastic quartz-feldspar-sericite schist."

The Totatlanika Schist has been mapped by Gilbert and Redman (1977), Hickman and Craddock (1976), Gilbert and Bundtzen (1976), and Gilbert (1977) both east and west of the type area described by Wahrhaftig (1968). The Totatlanika Schist in the Kantishna Hills has been mapped as five units: (1) metasandstone, metatuff(?), metachert, and minor greenstone (Mts), (2) metarhyolite porphyry, metafelsite, and sericite schist (Mtr), (3) metabasalt, tuffaceous phyllite, and metachert (Mtb), (4) marble and minor green phyllite (Mtm), and (5) undifferentiated metasedimentary and metavolcanic rocks (Mtms). A stratigraphic section is provided in Figure 22. The Totatlanika Schist is not a true schist in the textural sense; rather metamorphic fabrics vary from massive in metavolcanic rocks to phyllitic in meta sedimentary units. Map units on plate 1 are recognizable lithologic variants of the Totatlanika Schist and formalized members such as those described by Wahrhaftig (1968) have not been distinguished during this study. However, the Mtb unit may be roughly equivalent to the Chute Creek Member; the Mtr unit may be equivalent to either the California Creek or the Moose Creek member; and the overlying Mts, Mtm, and Mtms units are almost certainly equivalent to the Sheep Creek Member. Complex interfingering relationships between the various lithologies both locally and regionally make the above correlations very tenuous.

As suggested by previous workers, the Totatlanika Schist is dominantly of volcanic and volcaniclastic origin. Whole rock chemistry and stratigraphic relationships suggest that the Totatlanika Schist meta-igneous rocks probably represent calc-alkaline volcanism active during an early stage of subduction along a continental margin (Gilbert and Bundtzen, 1979).

Metabasite and chert (Mtb)

Metabasalt, meta-andesite, and intercalated jasperoidal metachert, finely bedded limestone, and metatuff form the bulk of the Mtb unit; it is exposed in a distincontinuous belt in the Chitsia Creek area and in a small outcrop area south of Crookee Creek (pl. 1). The Mtb unit generally forms the basal portion of the Totatlanika Schist but locally overlies Mts and Mtr lithologies. South of Crooked Creek, Mtb is believed to be interbedded with the upper part of the Keevy Peak Formation. The Mtb unit achieves a maximum thickness in the Chitsia Creek area of 250 meters.

About 80% of the Mtb unit forms resistant ridges, isolated knobs, and cliff exposures of olive gray to dark greenish gray, locally limonitized, metabasalt, metaga bbro, and meta-andesite. Textures in these meta-igneous rocks vary from aphanitic to coarse grained phaneritic but fine grained equigranular textures predominate. Amygdaloidal zones are less resistant and form limonitically stained rubble in depressions and saddles. Mtb meta-igneous rocks are largely unfoliated with primary igneous textures well preserved but a few localities exhibit subschistose varieties. Individual flows, when recognizable, display spheroidal weathering suggestive of pillow structure (shown on plate 1 as 's'), particularly when enveloped in metasedimentary rocks.

Relict phenocrysts and amygdules are readily visible in hand specimen, but thin sections show that almost all of the original mineralogy has been replaced or altered by secondary minerals. Thin sections from exposures south of Crooked Creek have a few relict original clinopyroxene(?) grains that have been almost completely replaced by actinolite, chlorite, and opaque minerals. Dusty albite laths are flecked with sericite. Carbonate and white mica comprise a few percent of the sample. Metabasalt from the Chitsia Creek section to the north usually contain completely replaced mineralogy with common assemblages including actinolite, chlorite, clinozoisite, albite, ilmenite, and leucoxene in a brownish tan amorphous mass of hematite and undetermined opaque minerals.

Amygdaloidal metabasalts and meta-andesites contain approximately 20% almond shaped, calcite filled amygdules up to 5 mm long oriented parallel to flow banding. The amygdules are filled with a core of quartz and pumpellyite(?) (one section) and rimmed with penninite. Within the very fine grained groundmass, sericite, albite microlites, intersitital. chlorite, and leucoxene(?) grains swirl around the amygdules and are probably the textural relicts of the original igneous melt. Magnetite and/or ilmenite are found as reaction rims around amygdules.

Although most metabasites are believed to be extrusive rocks, a few isolated knobs and zones within the Mtb unit 2 km southwest of Chitsia Mountain are medium to coarse grained, equigranular, pyroxene metagabbro plugs or sills. In thin section, these rocks are composed of clinopyroxene nearly completely altered to actinolite, chlorite (mainly penninite), epidote group minerals, leucoxene, and undetermined opaque minerals. Dusty plagioclase laths, rarely fresh enough to determine a relict composition (An 35-40), are completely albitized and flecked with sericite. The groundmass consists of fine grained magnetite, secondary leucoxene, ilmenite(?), chlorite (which gives the entire rock a greenish tinge), epidote, feldspar, and a pervasive, unidentified brownish amorphous substance--possibly very fine grained sphene. These metagabbros form small

(< 1 km^2) elliptical masses within the Mtb section and may represent feeders or centers of the mafic Mtb volcanism.

Some Mtb metavolcanic exposures west of Chitsia Creek are medium to dark gray, schistose, graphite and magnetite rich meta-andesite breccias and crystal tuff difficult to distinguish between graphitic rich, foliated units in the Birch Creek Schist and Keevy Peak Formation. One thin section of meta-andesite crystal(?) tuff shows albitized plagioclase laths and lapilli(?) fragments of chloritized hornblende, quartz, magnetite, and plagioclase in a needle-shaped albite rich groundmass. The dark color is due to abundant interstitial graphite(?) and magnetite grains.

Metasedimentary rocks comprise about 20% of the Mtb unit and generally form thin 5-30 meter thick beds between meta-igneous flow sequences. Olive to medium-green, tan weathered, banded phyllite consists of alternating 1 mm to 1 cm laminations of chlorite and light green horizons composed of very fine grained quartz grains with interstitial chlorite. The clay-like laminations are believed to represent original volcanic ash layers deposited in a tuffaceous cherty environment. The banded tuffs are intercalated throughout the Mtb unit, but one horizon associated with limestone and jasperoidal cherts about 2/3 through the section served as a 'marker bed' for about 7 km along strike immediately east and west of Chitsia Creek. Reddish, banded to brecciated, hematite rich, jasperoidal cherts and light gray, finely laminated limestone are intermittantly interbedded with other Mtb lithologies. The chert is dominantly a mixture of fine grained hematite and quartz grains with minor wisps of pure dark gray silica. Thermal alteration of the chert has recrystallized quartz into radiating spheres in a granoblastic matrix of magnetitie, hematite and quartz. The interbedded limestone shows little evidence of recrystallization. Graded beds of very fine carbonate grains and quartz observed in outcrop suggest that the Mtb unit west of Chitsia Creek is right-side-up. Secondary coarse grained calcite veins cut the limestone outcrops. The textural and structural features observed in the metasedimentary rocks suggest that they were deposited in a low energy environment below wave base between cycles of mafic volcanic eruptive activity.

Metarhyolite porphyry and sericite schist (Mtr-f,c)

Metarhyolite porphyry or augen gneiss and metafelsite are distinctive Totatlanika Schist lithologies and previous workers such as Prindle (1907), Brooks (1911), Capps (1912), Ragan and Horlocker (1962), and Wahrhaftig (1968) have debated the origin of the large quartz and K-spar 'augen' or 'buttons' in the coarse grained varieties (fig. 26). The Mtr unit in the study area forms resistant lens shaped accumulations midway through the Totatlanika Schist section in the Chitsia Creek and Crooked Creek-Toklat River areas. Two major facies were mapped: (1) an aphanitic to fine grained, locally porphyritic, limonitically stained, pyrite rich metafelsite ranging in composition from rhyolite to dacite (Mtr-f) and (2) a very coarse grained, K-spar (usually perthitic microcline)-quartz-sericite metarhyolite porphyry or 'augen gneiss' (Mtr).

The aphanitic-to-fine grained metafelsite forms a thick felsite center almost 300 meters thick 5 km southwest of Chitsia Creek. These rocks form both resistant knobs and nonresistant rubble depending on their silica content, alteration and degree of shearing. A common

Figure 26. Cataclastic metarhyolite porphyry, Mtr unit. Note very large sheared alkali feldspar grains. One sample of feldspar X-rayed by James Bond from this locality is microcline.

structural feature is platy cleavage with 1-3 cm thick furrowed, lightweight plates that form floating scree slopes. The concentric and irregular surfaces of these plates are believed to be original volcanic flow surfaces. Some fine grained Mtr units contain enechalon quartz veins along fractures (fig. 27). This veining, usually confined to the Mtr-f unit, does not penetrate underlying or overlying lithologies. Fresh samples are usually light gray finely laminated, sheared, siliceous aphanite; but some dark gray varieties are present and can be confused with mafic metavolcanic rocks of the Mtb unit.

Mtr-f metafelsite consists of relict euhedral, carlsbad twinned phenocrysts(?) of albite and alkali feldspar grains up to 5 mm long in a fluidal groundmass of sodic plagioclase, alkali feldspar microlites(?), chlorite and sericite (fig. 28). Fine grained brown biotite and quartz veinlets cut rock fabric. Isolated rhomb shaped secondary(?) calcite grains up to 3 mm in long dimension are extensively altering to limonite and sericite.

Sheared Mtr-f metavolcanic rocks are more common than unsheared varieties and display cataclastic textures. In samples from Crooked Creek, relict phenocrysts(?) of alkali feldspar and quartz have been broken and rotated. Fractures cutting the phenocrysts(?) are filled with sericite. Some fragmental grains show embayed contacts, suggestive of resorption channels in an igneous melt. Alkali feldspar phenocrysts(?) show graphic intergrowths of quartz and orthoclase. Opaque mineralogy constitutes $<$ 5% of the samples and is usually pyrite or magnetite. Secondary biotite-quartz veinlets invade the fabric. Limonite filled

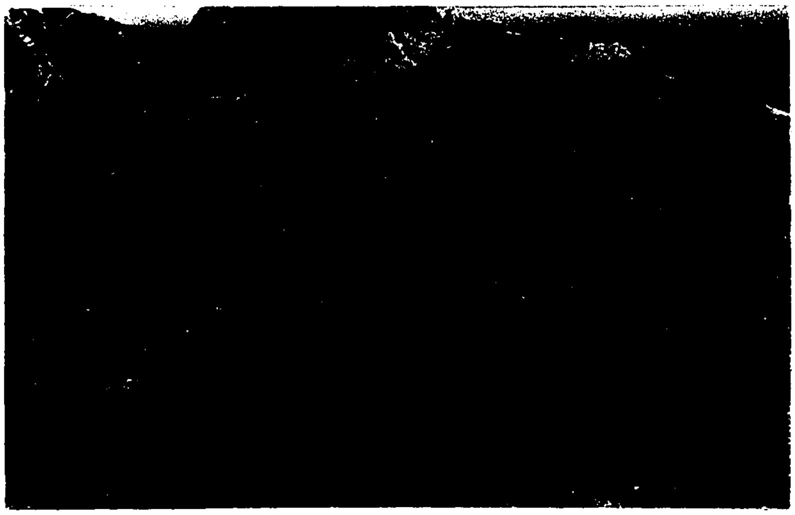


Figure 27. Very fine grained metafelsite (Mtr-f), 4 km west of Chitsia Mountain. Quartz veining is confined to metafelsite layer and does not penetrate underlying or overlying lithologies (75Ast1672).

Figure 28. Photomicrograph of metafelsite 2 km west of Chitsia Creek. Note large relict alkali-feldspar phenocrysts in groundmass of fine alkali feldspar, white mica, and quartz (crossed nicols; 75 Ast 1668b).

fractures in the sericite-chlorite rich zones often extend into the quartz-feldspar groundmass and sometimes into the relict phenocrysts(?).

Fairly large outcrop areas of Mtr-f (up to 15 km^2) contain up to 35% pyrite in both disseminated and massive form; these areas are shown on plate one in a stipled pattern. Where altered, the pyrite rich zones form distinctive limonite gossan.

Coarse grained "augen gneiss" or metarhyolite porphyry forms very resistant cliff exposures, knobs, and hills in the study area. The steep and rugged Chitsia Mountain area is largely cored by this coarse grained Mtr unit. This unit ranges in color from a tan to greenish-gray and contain quartz-feldspar masses and veins intruding through steep joint sets. Quartz grains are commonly rounded, show embayed contacts, and exhibit biaxial character (2V = 10°) suggestive of strain deformation (fig. 29). Most samples contain huge alkali feldspar and quartz 'buttons' or 'augen' up to 10 cm in length; these are usually elongated parallel to foliation and are sometimes trimmed or broken by cataclasis (fig. 30). Quartz grains are 1/2 to 1/5 as large as the K-feldspar augen. Thin sections exhibit several types of 'augen;' in order from most to least common-microcline(?) with classic gridiron texture, quartz or sodic plagioclase. Relict orthoclase(?) altering to microcline was observed in sections from Chitsia Mountain. Coarser grained metarhyolite porphyry or 'augen gneiss' can grade into quartz-alkali feldspar-sericite schist and phyllite along strike with more massive unfoliated varieties in thickened domical accumulations and more schistose rocks within thin discontinuous Mtr rock bodies.

Figure 29. Photomicrograph of metafelsite, Mtr unit, south flank of Chitsia Mountain. Note resorption channels in quartz grain (crossed nicols; 75Ast1659).

Figure 30. Photomicrograph of metafelsite, Mtr unit showing trimmed and brecciated quartz phenocrysts in a groundmass of alkali feldspar, white mica, quartz and chlorite (crossed nicols; 75 Ast 2929).

X-ray analysis from 2 samples of alkali feldspar buttons in the coarse grained Mtr unit show microcline and/or low temperature orthoclase compositions (J. Bond, oral commun.). The presence of large microcline crystals can suggest several things: (1) they may have originally been igneous orthoclase phenocrysts recrystallized to microcline during regional metamorphism (Winkler, 1967); (2) they may be original microcline phenocrysts in a coarse grained igneous melt which almost certainly indicates an intrusive mode of crystallization; (3) as suggested by Ragan and Horlocker (1962) the large microcline augen may have grown from smaller grains during regional metamorphism and are not relict igneous phenocrysts at all. The coarse grained nature and geometric configurations of Mtr exposures indicate that thick metarhyolite bodies are domes intrusive into the metasedimentary Mts section that probably represent feeders and/or centers of Totatlanika Schist volcanism, consistent with established models of rhyolitic eruptive sequencies (Compton, 1962, p. 250-271). Zoning in some of the large K-feldspar augen described by Ragan and Horlocker (1962) from the Totatlanika River localities is also present in Mtr units in the study area. Some growth around smaller K-spar grains has likely occurred; however, the textural and compositional evidence presented here suggests that the Mtr unit represents an original series of fine grained eruptive rhyolites and dacites and hybabyssal intrusions that formed part of a volcanic arc during and prior to deposition of metasedimentary rocks of the Totatlanika Schist. Whole rock major oxide analyses reported by Gilbert and Bundtzen (1979) and those presented in table 1 and plotted on an AFM projection (fig. 9) and alkali-silica diagram (fig. 10) demonstrate calc-alkaline afinities for these meta-igneous rocks.

Volcaniclastic metasandstone, tuffaceous phyllite, and minor greenschist (Mts)

A thick heterogeneous sequence of dominantly metasedimentary rocks lies below, is interbedded with, and caps major metavolcanic horizons in the Totatlanika schist. The Mts unit imperceptively grades from greenish gray, highly tuffaceous graphitic rich phyllites and minor metasandstone near the base of the Totatlanika Schist section to dominantly greenish to maroon metasandstones and calcareous phyllite near the top. The volcaniclastic nature of Mts metasandstones decreases gradually upward through the section. All Mts lithlogies are more or less nonresistant and form friable, nonresistant outcrops and bedrock rubble.

Medium gray to light green, tuffaceous phyllite consists of alternating thin layers and lenses of interlocking chlorite, white mica, quartz, graphite, calcite and minor clinozoisite that range in thickness from 5 mm to 2 cm. In both outcrop and hand specimen, mica sheens are well developed. The greenish chlorite-white mica-quartz layers are believed to be relict water laid tuff(?); darker gray varieties are probably organic rich mud--both deposited in a shallow marine environment. Angular shaped, coarse-grained, chlorite-actinolite-leucoxene aggregates up to 1 cm in diameter are nested in some of the chlorite rich layers and could represent relict igneous crystals in a water laid tuff(?). This rock type grades from dominantly greenish chlorite rich layers to essentially pure medium gray calcareous graphite rich varieties. All types of tuffaceous phyllites are invariably calcareous and will effervesce with application of hydrochloric acid.

Medium green, fine to coarse grained, porphyroclastic quartz phyllite to semischist is the most abundant rock type in the Mts unit; it also comprises a substantial portion of the Mtms unit. In the field, this rock type was thought to be a true greenschist (mafic meta-igneous rock); however, examination of thin sections indicate these lithologies are predominantly tuffaceous and/or volcaniclastic metasandstones composed of subangular to rounded clasts of quartz (60%), albite (20%; An0-8), and felsite lapilli (10%) in a groundmass of undetermined feldspar, quartz, epidote, sericite, and penninite. The distinctive green color is due to interstitial penninite in the groundmass that locally makes up to 10% of a given sample. The 'blue quartz-eyes' or porphyroclasts are believed to be relict sedimentary clasts of quartz. Most clasts are stretched and elongated, and most samples exhibit a cataclastic fabric. There is a continuum of clast size ranging from silt to pebbles as large as 1 cm in diameter--sand sized clasts are the most common. Occasional wisps and lenses up to 1 cm thick of almost pure penninite are laminated in the metasandstone. Due to the high chlorite, white mica and plagioclase (albite) content, these rocks are believed to have been originally volcaniclastic sandstones with some beds appearing to imperceptively grade into tuffaceous phyllite and metamorphosed tuff (fig. 31). Major oxide analyses of two porphyroclastic quartz semichist of the Mts unit (Table 1, No. 28, 27) are similar to those of graywacke reported by Pettijohn (1957).

Figure 31. Photomicrograph of metasandstone, Mtms unit; (q) qtz, (a) albite, (g) groundmass of chlorite, white mica, quartz and undetermined feldspar (crossed nicols; 75 Ast 1732).

Near the top of the Mts section are minor but distinctive interbeds of green and maroon phyllites and slate that collectively comprise approximately 2-3% of the Mts unit. They usually occur in beds less than 1 m thick within the metasandstone layers. The maroon and green colors are caused by interstitial hematite and chlorite respectively in a very fine grained groundmass of quartz, feldspar, sericite, and opaque minerals.

Very minor 1-meter-thick intercalations of actinolite bearing-chlorite rich greenschist are interbedded with the Mts unit, particularly near the top of the section. Thin sections show them to be composed of actinolite with overgrowths of chlorite and tremolite, albitized plagioclase, layers of clinozoisite, interstitial chlorite, in a quartz-feldspar-opaque groundmass.

Marble and minor greenschist (Mtm)

Recrystallized limestone and marble intercalated with unmappable Mts phyllites and metasandstone comprise the Mtm unit in the northern part of the study area (fig. 32). It overlies most of the Mts unit and essentially all of the metavolcanic lithologies of the Totatlanika Schist. It forms moderately resistant hogback ridges and steep scree slopes due in part to its strike orientation perpendicular to northerly direction of stream flow. Lush green meadows of grass and shrubs grow on more flat lying surfaces, due to the high lime content.

The Mtm unit contains about 90% finely laminated, light to medium gray, fine grained marble beds that grade from almost pure calcite to calcareous sandstone. Weathering and results in a hackly-pitted surface. Several ages of secondary remobilized quartz-calcite veinlets a few a

b

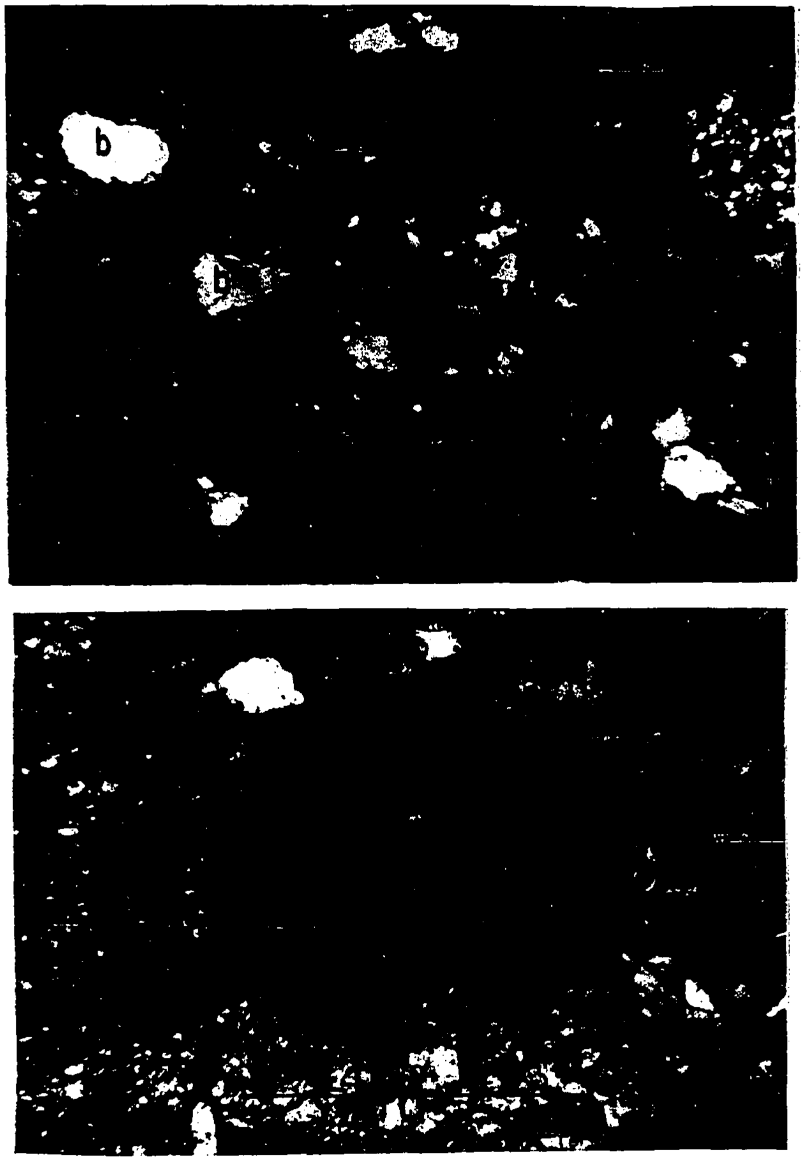


Figure 32a-b. a) Photomicrograph of cataclastic impure marble showing grains of (b) quartz and (c) calcite in calcite matrix (crossed nicols; 75 Ast 1703). b) Echinoid spine(?) or sponge spicule found in thin section described in a).

millimeters thick cut most outcrops and some dolomitization along fracture systems has taken place.

Undifferentiated metasedimentary rocks (Mtms)

A heterogeneous unit of metasedimentary rocks caps all Totatlanika Schist units. Because it contains a mixture of cataclastic metasandstone, tuffaceous phyllite, marble, and green and maroon slate and phyllite previous described in the Mtm and Mts units, it has been lumped as the Mtms unit. Thin sections are composed of chlorite + quartz + albite + clinozoisite, and white mica. Most of the mapping control consists of talus and slaty rubble in low vegetated hills at the northern extreme of the Kantishna Hills. A few intercalated greenschist horizons are probably isolated metamorphosed mafic volcanic flows or tuffaceous sedimentary beds.

Metamorphism

The Totatlanika Schist has, by and large, undergone a 'low grade' regional metamorphism (Winkler, 1967). Like the Keevy Peak Formation, a large component of the regional metamorphism has been dynamic rather than thermal, as evidence by the extensive cataclastic textures developed in many of the exposures. Table 7 and ACF-AKF projections (fig. 33-34) summarize mineral assemblages present in the various Totatlanika Schist rock compositions. Mafic metavolcanic rocks (Mtb unit) and metasandstones (Mts) contain actinolite + epidote + albite + sericite ± chlorite compatible with a chlorite zone greenschist facies assignment for intermediate to mafic rocks (Winkler, 1967). Mtr metarhyolite porphyry specimens show relict microcline after relict alkali feldspar indicating a low grade of

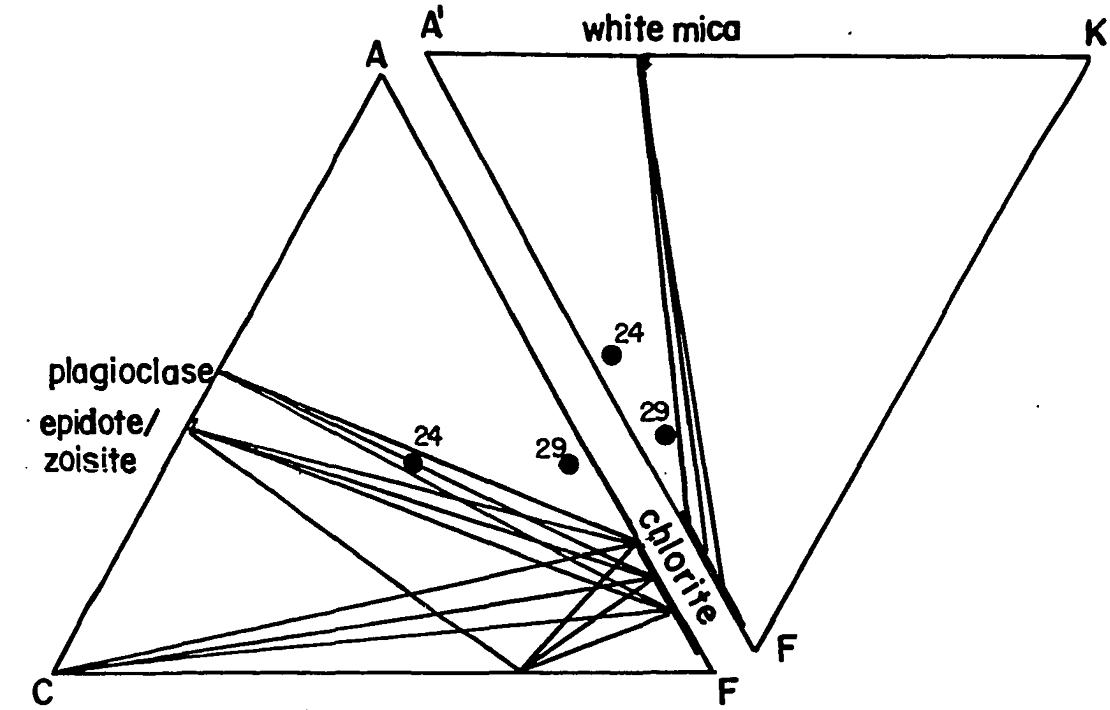


Figure 33. ACF-A'KF projection of 22 basic and intermediate rocks from Totatlanika Schist.

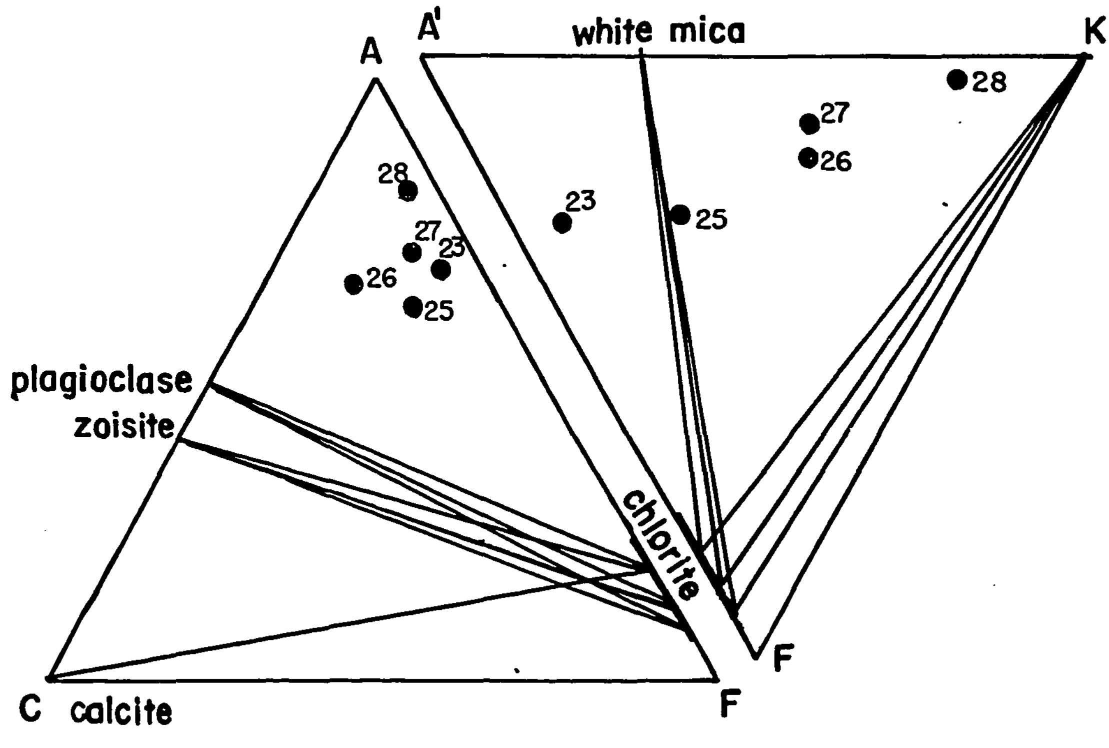


Figure 34. ACF-A'KF projection of 21 metafelsites from the Totatlanika Schist; major oxide plots from table 1.

regional metamorphism. Many exposures and thin sections appear virtually unmetamorphosed in the thermal sense; rather dynamic deformation has been the primary change from the original igneous or sedimentary rock protoliths. Many samples of metafelsite do not contain recognizable mineral assemblages necessary for a definitive metamorphic facies classification.

Mica crenulations, secondary cleavage, and isoclinal folding are common in noncompetent Totatlanika Schist metasedimentary rocks, but virtually absent in meta-igneous rocks. No mineral assemblages are in disequilibrium except those contrasting with relict igneous or sedimentary minerals.

Age

Prindle (1907) and Brooks (1911) regarded metarhyolite in the Bonnifield mining district now mapped as Totatlanika Schist as Silurian to Lower Devonian in age, based on regional stratigraphic relationships in interior Alaska.

On whole rock K-Ar analysis from metarhyolite (Mtr) east of Chitsia mtn. (pl. 1; loc. 7) has yielded an age of 108.0 ± 3.2 m.y. Bundtzen and Turner (1979) believe this age represents the lower greenschist facies metamorphism recognized in the Totatlanika Rock Schist mineral assemblages and the retrograde event that overprinted higher grade metamorphism in the Birch Creek Schist. W. G. Gilbert (pers. communication) has obtained an ^{40}K-^{40}Ar actinolite age date of 164 m.y. from Totatlanika Schist metabasite near Wood River 120 km east of the study area. Sherwood (1979) has obtained a 309 m.y. ^{40}K-^{40}Ar age from actinolite in a Paleozoic metabasite unit in the Healy D-2 Quadrangle. Both of these ages could represent either (1) a partial reset or recrystallization of an original igneous melt during Cretaceous time, or (2) a pre-Jurassic metamorphism.

R. B. Blodgett (Oregon State University) failed to find conodonts or other fauna in five Mtm samples submitted by the author. One thin section from a thin marble lens in the Mtb unit near Chitsia Mtn contains echinoid spines of nondianostic age. Wahrhaftig (1968) assigned the Totatlanika Schist a Mississippian(?) age, based on a Syringapora bearing fossil locality in the Healy D-2 Quadrangle. Hickman and Craddock (1976) have reported an Upper Devonian fossil assemblage in rocks correlative with the Totatlanika Schist near Wood River. Stratigraphic, structural, and fossil evidence reported by previous workers led Gilbert and Bundtzen (1979) to assign the Totatlanika Schist an Upper Devonian to Mississippian age; they also correlated the unit with a belt of meta-igneous rocks of Mississippian age in the Pelly Mtns. of Yukon Territory (Morin, 1977).

Metarhyolite (Mtr) and metabasalt (Mtb) are believed to be interbedded with the Keevy Peak Formation on Crooked Creek and east of the Toklat River. Assuming that this conformable relationship holds true, the Totatlanika Schist eruptive rocks are believed to be contemporaneous with the metasedimentary rocks of the Keevy Peak Formation.

Mesozoic-Cenozoic Igneous Rocks

Introduction

The Kantishna Hills is remarkably devoid of large intrusive masses. Only small plugs, dikes, and sills have escaped regional dynamo-thermal metamorphism and many of these have been hydrothermally altered. Three major subdivision of igneous intrusions have been mapped and shown on the geologic map (pl. 1) as: (1) altered rhyolite sills (Tqr), (2) a complex dike swarm consisting of augite olivine gabbro or basalt (Tb), quartz-Kspar porphyry (Tf), hornblende bearing dacite (Thd), and one recognized ultramafic dike (Tu), and (3) an altered granodiorite sill. These igneous rocks are implaced along faults, and at the crest of anticlines.

Altered quartz rhyolite (Tqr)

A series of at least six small sill—like bodies of altred rhyolite intrude subparallel to foliation in Keevy Peak Formation calcareous schist and phyllite (Pks, pl. 1) in the northern Kantishna Hills; some may have intruded along thrust faults. These small sills average less than 1/2 km^2 in size and are roughly elliptical in shape. Tqr forms moderately resistant, blocky outcrops along the top of a northeast trending ridgeline that contrast with nearby nonresistant metamorphic rocks. Most exposures are pale brown to grayish orange, fine grained, 'sugary' felsites. In thin section Tqr consists of undetermined K-feldspar, quartz and plagioclase grains extensively altering to clay minerals and sericite. The entire ground mass is inclusion charged. Former platy minerals, probably biotite, have been completely propylitzed to magnetite and limonite. Small muscovite grains are scattered in aggregates throughout the ground mass. Secondary quartz-adularia veins 1 cm in width cut the rock exposures. Chemical and model analyses (tab. 1 and 7) indicate a calc-alkaline rhyolite or granitic composition.

Age. No radiometric ages are available for the altred rhyolite (Tqr), these rocks are too altered to be suitable for the conventional ^{40}K-^{40}Ar dating method. The Tqr unit is younger than the mid-Cretaceous regional metamorphic event that afffected host Keevy Peak Formation lithologies, and could be correlated with the dike swarm and small plugs (Tb, Tf, Thd) of early to mid Tertiary age in the southern and east central Kantishna Hills. However ubiqutous alteration indicates that the Tqr unit could be older than the southerly dike swarm.

Mafic to felsic dikes and plugs (Tf, Tb, Thd, Tu)

At least 40 basalt or gabbro, quartz-K-spar porphyry, and dacite dikes and small plugs crop out in a 30 kilometer long northeasterly trending belt extending from the headwaters of Eldorado Creek to the Clearwater Fork of the Toklat River. There are a few larger masses that attain two km^2 in size, but most intrusions vary from 2-10 m thick and rarely continue laterally for more than 2 km; thus most are schematically shown on plate 1.

Olivine augite gabbro and/or basalt (Tb) comprize the most dominant composition and accounts for approximately 75% of all the bodies in the dike swarm. Morrison (1964) classified mafic intrusions in his thesis area as augite olivine gabbro, sanidine bearing augite gabbro, and olivine diabase; all variants have been lumped in this report as the Tb unit due to their mineralogical, textural, and chemical similarities. Exposures and rubble have dark orange to tan weathered surfaces, are medium to dark greenish gray on fresh surfaces, and sometimes form distinctive spheroids up to 1 m in diameter on ridge tops (fig. 35).

Fine grained gabbros or basalts (Tb) usually exhibit ophitic to lamphrophyric textures, but hypidiomorphic granular variants are found in the coarsest grained samples. In a few samples, parallel orientation of plagioclase laths are superimposed over the normal ophitic groundmass.

Figure 35. Spheroidal weathering of olivine-augite-gabbro dike (Tb) 3 km east of Banjo Mine (75 Ast 1958).

The dominant mineral assemblage in the Tb unit is sausuritized plagioclase ± quartz ± potassium feldspar (either orthoclase or sanidine) ± trace myrmekite ± augite ± olivine ± biotite ± opaque minerals (magnetite, rutile) and respective alteration products (fig. 36). Euhedral plagioclase grains and laths usually display oscillatory zoning with cores ranging from An 42-70 and rims An 37-45. Potassium feldspar usually consists of anhedral orthoclase or sanidine grains with patches of myrmekite enveloped in the K-spar grains. Ratios of plagioclase to K-feldspar range from 2.75:1 to 12:1 (tab. 7) and average about 7:1. Sausuritized feldspars are flecked or replaced with calcite rhombs, sericite, and minor chlorite. The dominant mafic mineral in most samples is euhedral titano-augite up to 5 mm in diameter often veined or replaced by antigorite, leucoxene, and chlorite. In olivine diabase, some samples contain up to 6.9% modal olivine (fig. 37, tab. 7), but in most gabbro or basalt samples, olivine is extensively replaced by iddingsite and opaques. Small anhedral isolated grains of biotite can make up to 6% of a speciman but usually average 2-3%. Hornblende is generally absent. Color index varies as low as 25 to as high as 60 with the dominant opaque minerals being magnetite or rutile, with a few sulfides present locally.

A boulder train of dark green boulders coated with chrysotile slickensides marks a serpentinized ultramafic dike (Tu) at the divide between Rainy and Spruce Creeks. The dike is composed of chlorite, carbonate, talc, non-directional tremolite, and antigorite clusters pseudomorphic after olivine(?) in a textural setting of extensive replacement mineralogy. Clusters and aggregates of tremolite may be alteration products of original

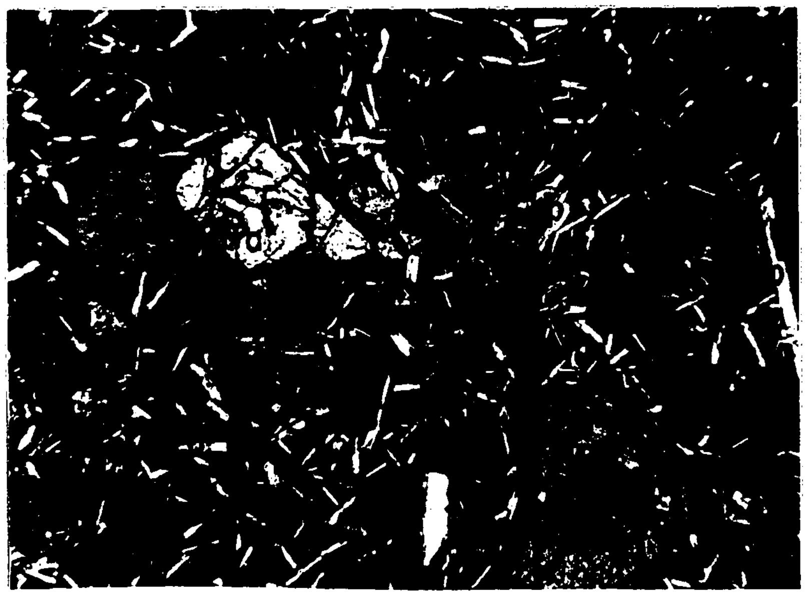


Figure 36. Photomicrograph of augite basalt dike, (a) augite (p) plagioclase (An 45-52) (crossed nicols; 76BT270).

Figure 37. Photomicrograph of medium grained, phaneritic, olivine-augite gabbro, (p) plagioclase (An 40-54), (o) olivine (a) augite, (b) biotite (crossed nicols; 76BTBan10).

pyroxene. Magnetite and apatite(?) comprize up to 25% of thin sections. One major oxide analysis (tab. 8) of the Tu dike attests to its ultramafic classification.

Brown to bleached, porphyritic quartz rich felsite dikes form resistant knobs, hogbacks and rubble throughout the dike trend. Ubiqutous pyrite forms distinctive limonitic alteration which makes Tf outcrops quite conspicuous. Textures range from porphyro-aphanitic to fine grained equigranular. The common porphyritic variants are composed of large amounts of rounded to equant quartz as both phenocrysts and groundmass grains, altered orthoclase, albite, ± perthitie, ± myrmekite, and primary muscovite in a groundmass of secondary(?) sericite, quartz-feldspar aggregates, calcite, chlorite, and limonite veins. Opaque minerals are usually sulfides (pyrite, very minor chalcopyrite), but some rutile needles are present. The groundmass in all thin sections is inclusion charged with apatite and zircon. Extensive carbonate in the groundmass is probably an alteration product of the feldspars. Plagioclase (An 5-10) can be found as small untwinned or twinned grains largely flecked or replaced by sericite, calcite and clay minerals. Many K-feldspar grains and phenocrysts are completely corroded to clay minerals (fig. 38). According to Morrison (1964, p. 62) the presence of 'beta' or high temperature quartz in quartz porphyry at the Bunnell prospect (pros. 4, pl. 1) indicates a crystallization temperature of 573-870°C. One sample of quartz orthoclase porphyry contains 42% myrmekite but the average of 6 thin sections is about 10% myrmekite (tab. 7).

Light to medium gray, usually fresh, hornblende dacite dikes (Thd; fig. 39) crop out in two restricted areas one east of Last Chance Creek

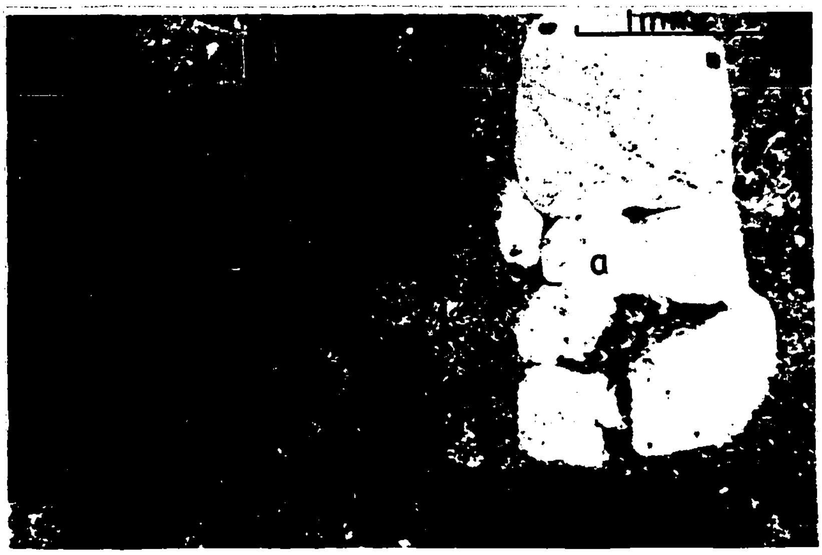


Figure 38. Photomicrograph of quartz-K-Spar porphyry body, Bunnell Prospect, (a) quartz, (o) orthoclase, (s) sericite-feldspar-quartz groundmass (crossed nicols; 75 Ast 1987).

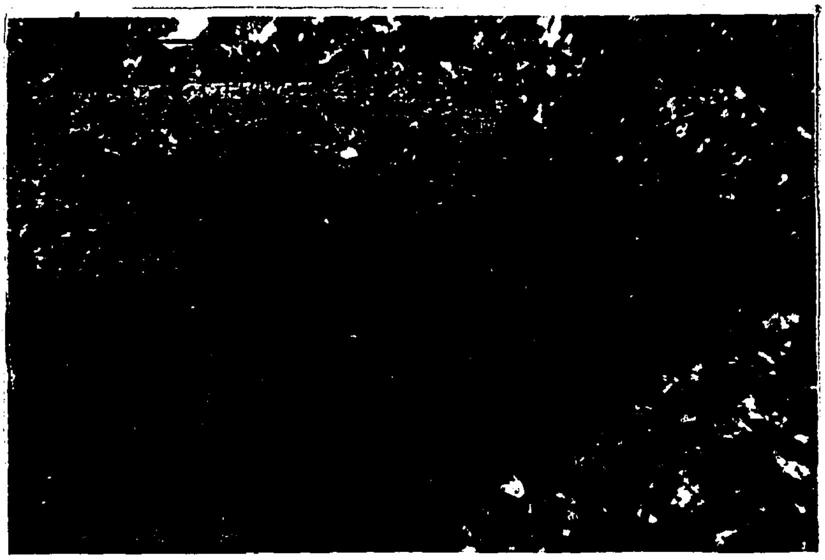


Figure 39. Photomicrograph of hornblende dacite dike (crossed nicols; 75 Ast 1859).

and another east of the Clearwater Fork of the Toklat River 6 miles south of Stampede (pl. 1). In thin section these rocks are composed of small plagioclase laths (An 20-35), large pleocroic blue green hornblende phenocrysts, and quartz-feldspar anhedral in an aphanitic 'sugary' feldspar-opaque groundmass. Large poikiloblastic orthoclase phenocrysts are slightly trimmed by sericite alteration.

Structure, chemistry and age. Most of the Tf, Tb, Tu, and Thd igneous bodies, particularly those in the Quigley Ridge and Stampede areas, are implaced along high angle longitudinal faults parallel to the 'Kantishna Anticline', a regional fold structure in the rocks. A stereonet plot (fig. 40) of 39 dike and plug allignments illustrates the dominant northeast trending high angle orientation of the dike swarm. A few dikes strike northwest and conjugate to the main intrusive alignment. When measurable, the dikes are either vertical or dip steeply with preferred dip orientation controlled by fracturing.

For the most part the dike swarm represents a bimodal differentiate of rhyolitic and basaltic calc-alkaline magma. Chemical analyses (tab. 8) of 4 gabbro or basalt bodies, 2 dacite dikes, and 2 quartz porphyry-rhyolite plugs suggest calc-alkaline afinities typical of continental margin volcanic belts. A plot of normative plagioclase verses normative color index utilizing the method described by Irvine and Barager (1971) shows 4 basalt, 2 andesite, 1 dacite, and 2 rhyolite compositions (fig. 41). Five of eight samples fall within the subalkaline field of a 'Macdonald-Katsura' alkali-silica diagram (fig. 42); however all four mafic dikes fall within the alkaline field of the alkali-silica diagram. Because these samples hae very high potassium-sodium ratios they could

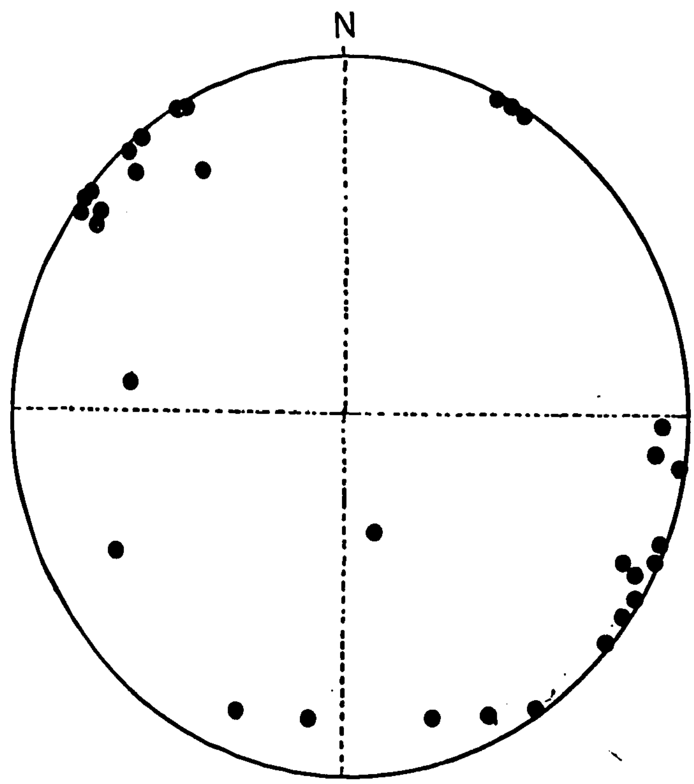


Figure 40. Stereographic projection of 39 dike orientations, Kantishna Hills.

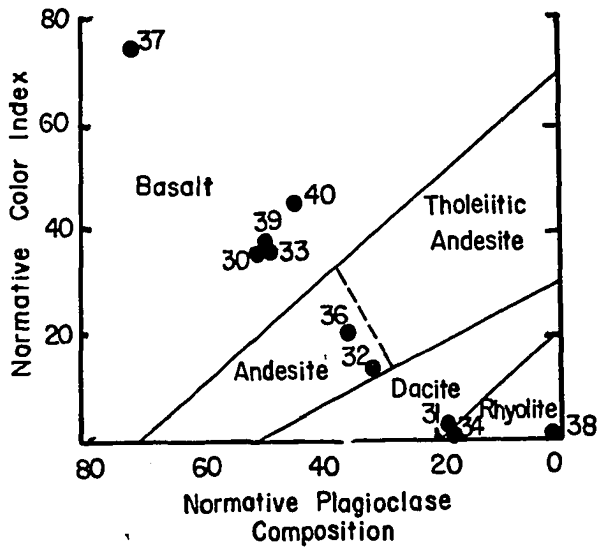


Figure 41. Plot of normative color index versus normative plagioclase composition for ten dikes from Kantishna Hills.

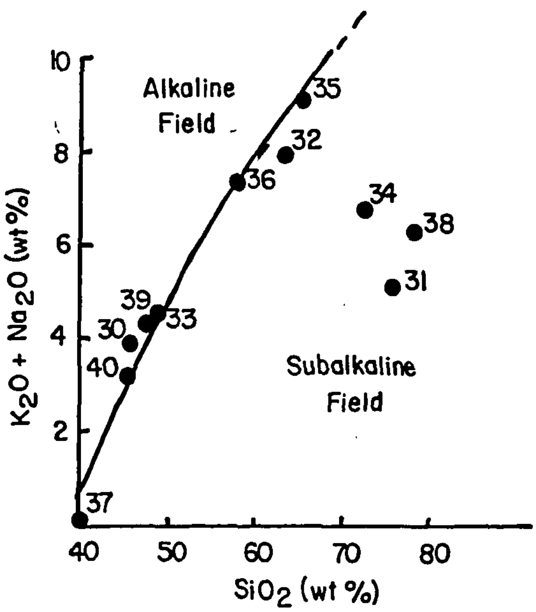


Figure 42. Alkali-silica diagram for eleven dikes and plugs from Kantishna Hills.

be classified as potassium enriched calc-alkaline rocks. The 8 samples plot within the calc-alkaline field of a standard A-F-M diagram (fig. 43). Calculation of an average Thorton and Tuttle (1960) differentiation index (DI) of 35.0 for the Tb samples indicates normal basic afinities while an average DI of 89 for both the Thd and Tf samples show a fairly normal rhyolitic - granitic series. Low sodium-potassium ratios, lack of iron enrichment, and generally high quartz content would suggest deep seated fractionation of hydrous parent material for the dike swarm as suggested by Yoder (1973). The existence of the ultramafic dike strengthens this interpretation.

However, the classification based on Al_2O_3 versus normative plagioclase (fig. 44) demonstrates that all four mafic dikes are alumina deficient and plot in the tholeiitic field. The puzzling lack of normative olivine in rocks that contain modal olivine, the euhedral mafic mineralogy in a sugar felsic groundmass, the lack of normative nepheline in any samples as well as the ubiqutous presence of modal alkali feldspar (tabs. 7, 8) suggest that the mafic dikes could be classified as lamprophyres. Similar lamphrophyre dikes have been described in the Wood River (Freeman, 1980) and the Robertson River areas (Foley, 1981) of the central and eastern Alaska Range respectively. Chayes (1966) has suggested that nepheline normative basalts represent the only unquestionably alkaline basalt variety. Perhaps the Kantishna mafic dikes are transitional and possess both alkaline and subalkaline characteristics. Overall, the chemistry and mineralogy of the Tf, Tb, and Thd igneous bodies are similar to results reported by Gilbert, Ferrell, and Turner (1976) from the Teklanika

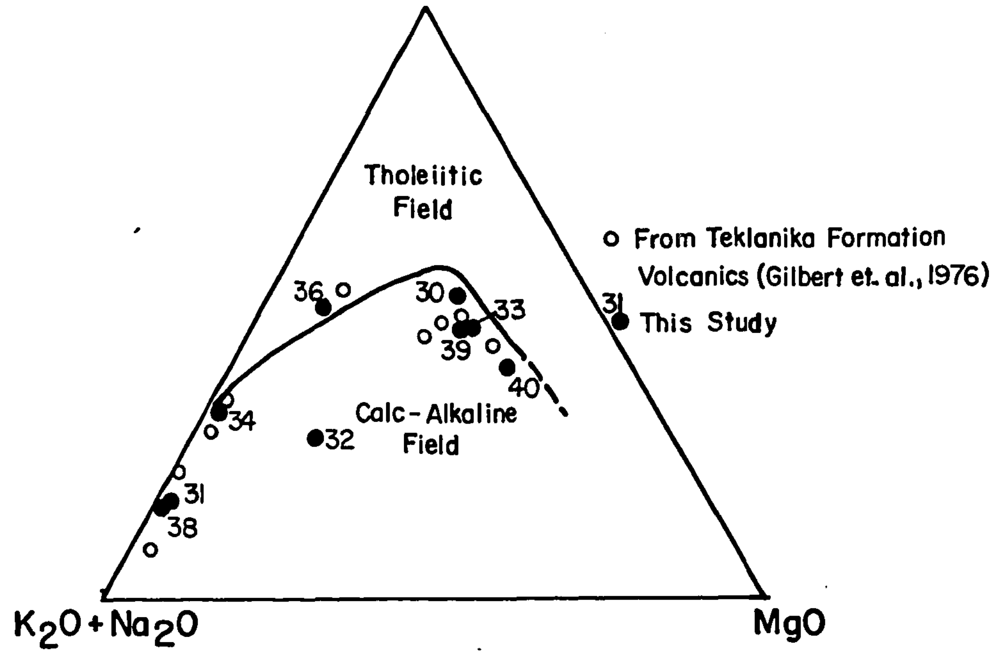


Figure 43. AFM projection showing nine dikes from Kantishna Hills and nine rocks from the Teklanika Formation (Gilbert and others, 1976).

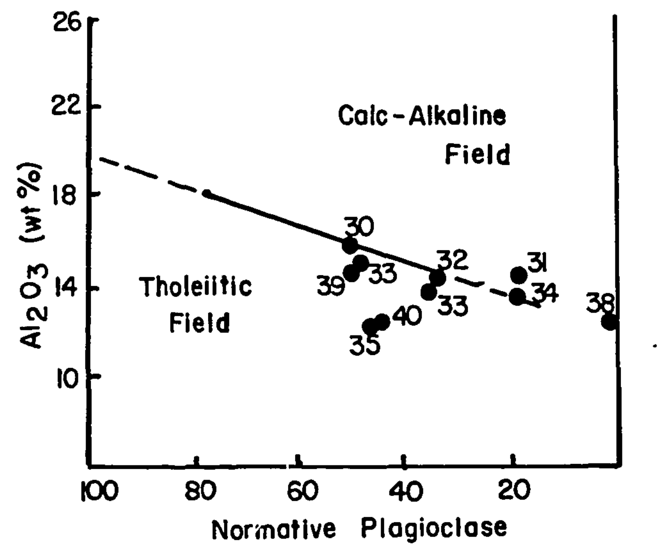


Figure 44. Al_2O_3-normative plagioclase diagram after Irvine and Barager (1971), showing ten dikes from Kantishna Hills.

Formation Volcanics east of the Kantishna Hills in the Polychrome-Sable Pass area.

Bundtzen and Turner (1979) have reported four $^{40}K-^{40}Ar$ ages from the Tf, Tb, and Thd units. Three of the ages, two from gabbros (Tb) and one from quartz-orthoclase porphyry (Tf), average 49.8 m.y. but a fourth from a dacite (Thd) dike yields an amphibole age of 81.3 + 2.4 m.y. The 49.8 m.y. average age of three samples suggests that they may be related to late stage Teklanika Formation volcanics which crop out throughout the central Alaska Range (Gilbert and others, 1976). Seven potassium-argon ages from the Teklanika Formations reported by Hickman (1974) and Gilbert, Ferrell, and Turner (1976) range in age from 49.5 to 60.6 m.y., consistent with ages of the Tb and Tf dikes in the Kantishna Hills. Based on similar mineralogy, chemistry, and age, the Tb, Tf, Tu, and tentatively Thd dikes and plugs are regarded as late stage Teklanika Formation differentiates of Early Paleocene to Eocene age.

Granodiorite to quartz monzonite sill (Tgd)

A hypidiomorphic granular to porphyritic granodiorite to quartz monzonite sill crops out in the southeastern portion of the study area near the old Mt. McKinley National Park boundary. The sill forms a prominant wall 3-5 m high and about 300 m wide for over 5 km in a north-easterly direction near Gorge Creek where it leaves the map area. Helicopter reconnaissance in 1975 located 3 isolated outcrops of similar intrusive rock 8 km south of the Gorge Creek sill. These outcrops are believed to be part of the 'Stoney Creek' granodiorite which mainly crops out on Stoney Creek and tributaries in Denali National Park.

Two thin sections of Tgd are composed of myrmekite, plagioclase (An 22-30) phenocrysts, hornblende, biotite, perthitic orthoclase and associated alteration minerals in a finer grained interlocking matrix of myrmekite, quartz, opaques, and undetermined feldspar. Modal analyses of one sample (tab. 7) contains 53.3% myrmekite. Both hornblende and biotite are extensively altered to limonite and chlorite. Euhedral andesine forms large phenocrysts up to 1.5 cm long.

No radiometric age control is available for the Tgd unit. Most samples show crude petrologic similarities to the 38 m.y. old Mt. Eielson pluton 30 km south of the study area. Additionally the SiO_2, K_2O, Na_2O and Al_2O_3 content of one sample from the Tgd sill (tab. 8) is similar to that reported for the Mt. Eielson pluton (Decker and Gilbert, 1978).

Hornfels and Associated Skarn (Th)

Descriptive geology

A number of widely scattered hornfels zones with associated skarns are developed in pelitic and carbonate rocks in the Kantishna Hills. They occur on Iron Dome near the mouth of Eldorado Creek, 4 kilometers upstream from the mouth of Little Caribou Creek, 3 1/2 km south of the Crooked Creek mine, and in scattered outcrops thorughout the Spruce Creek-Kankone Peak area. Most of these thermally altered rocks constitute small, poorly defined subcircular to elliptical areas of about 1/2 sq km each and are recognized on the basis of mineralogy and texture. No large intrusives are related to them. They are developed chiefly in calcareous rocks, but some pelitic schists or metamorphosed marls (?) have also undergone thermal alteration.

Two thin sections from thermally metamorphosed rocks on Iron Dome contain clinozoisite, microcline, vesuvianite (or idocrase), and garnet as major mineralogical constitutents. Compositional segregation in the form of garnet-calcite-wollastonite(?) aggregates, veins of microcline and plagioclase, and large masses of clinozoisite-chlorite-microcline-vesuvianite grains overprint previous regional foliation in the original marbles. Locally, metalliferous skarn consisting of massive pyrite and undetermined fine sulfides has developed in isolated pods.

Hornfels outcropping south of the Crooked Creek mine consist of dull to olive green, very fine grained massive tactite. Thin sections show hornblende-epidote-chlorite-albite-calcite mineral assemblages in a well developed granoblastic texture. The hornblende occurs as long rod like porphyroblasts up to 1 cm long randomly oriented throughout the finer grained epidote rich groundmass; calcite forms reaction rims with the tourmaline locally. Interlocking epidote grains can comprize up to 70% of a given rock specimen. No garnets were recognized. One sample in the hornfels zone contains a subeliptical mass of carbonate charged with clinozoisite and rimmed with sphene. The overall gross mineralogy of the rock is epidote (50%), hornblende (25%), plagioclase (20%), and opaques (5%). This carbonate mass could be a relict amygdule of an original basic volcanic rock. In one area metalliferous skarn has developed in the tactite. There, massive hematite layers, with associated veins and fracture fillings of chalcopyrite and sphalerite have replaced calcareous layers.

Hornfels and skarn overprinting regionally metamorphosed marble east of Little Caribou Creek contains a calcite-garnet-albite-hornblende-epidote mineral assemblage in a granoblastic matrix. Veins and segregations of magnetite up to 3 cm wide infill fractures or replace layers in the altered marble beds. Additionally, small < 1 mm clusters of chalcopyrite, galena and sphalerite are irregularly distributed in one small rock exposure.

Distinctive, brownish tan, medium- to coarse-grained tremolite rich schists have been examined east of Kankone Peak, west of Wickersham Dome, and about 1 km east of the Crooked Creek hornfels zone. The tremolite schist occurs as small discontinuous lenses interbedded in pelitic schist and amphibolite. In thin section these rocks are seen to be composed of elongated euhedral directionless tremolite crystals as much as 1 1/2 cm long and epidote group minerals that overprint an older matrix of xenoblastic quartz, albite, white mica, biotite, and accessory sphene. Near the Kankone Peak locality, one 5 cm thick layer contains 50% garnet which also overprints the older regional metamorphic fabric.

Metamorphic facies and age

No sizable intrusive masses are clearly associated with any of the hornfels-skarn zones described and the 'thermal engine' that produced the contact metamorphism is concealed. All hornfels and skarn overprint the last regional-dynamothermal metamorphic event that is believed to be of mid-Cretaceous age. The Ths unit probably developed as a result of igneous activity described previously but it is unclear which suite of intrusives are involved. A small gabbro dike (Tb) outcropping near the Crooked Creek occurrence (pl. 1) may be responsible for hornfels and skarn development there.

The Iron Dome statically metamorphized rocks may be transitional between the pyroxene hornfels and hornblende hornfels facies, based on the coexistance of diagnostic minerals common to both facies--vesuvianite or idocrase (pyroxene hornfels), muscovite, tremolite, hornblende, and chlorite (hornblende hornfels facies). According to Winkler (1967), the presence of epidote group minerals would indicate a lower temperature facies such as the albite-epidote hornfels series.

The unmapped zones east of Kankone Peak and west of Wickersham Dome do not contain a definitive mineral assemblage necessary for a facies classification but the garnet-tremolite-epidote-green biotite association would indicate a transition between the albite-epidote and hornblende hornfels metamorphic facies for those occurrences. The Crooked Creek and Little Caribou hornfels zones contain a hornblende-epidote-calcite-tremolite-quartz-chlorite assemblages that most likely represent the hornblende hornfels facies (Winkler, 1967, p. 74-79).

Tertiary Sediments (Ts)

Descriptive geology

Poorly consolidated sand, silt, and conglomerate beds overlie crystalline basement in topographic depressions flanking the Kantishna uplands. These non-resistant sedimentary rock beds are usually exposed along valley walls, in stream cuts and in broad, hummocky horizontal areas where erosion of the non-resistant rocks has produced classic "badlands" topography. Ts exposures in poorly exposed vegetated areas are composed of tan weathered surface cobbles indicating underlying Tertiary sediments.

Large Ts units shown on plate 1 in the lower Glacier Creek, upper Moose Creek, and Flume Creek-Chitisa Creek areas are inferred from aerial photographic interpretation and commonly covered with a thin veneer of terrace gravel. The Glacier-Caribou Creek basin was tested by mining exploratory shafts and churn drilling in earlier years. One shaft west of Glacier Creek encountered Tertiary gravels. According to Capps (1916, p. 298) "The shaft, after penetrating a few feet of ordinary bench gravels, encountered a body of white, rounded quartz gravel that continued without interruption for a depth of 114 feet at which sinking was discontinued without reaching bedrock." The material from the shaft dump was largely vein quartz, rounded and water worn, and ranged from sand size to cobbles 10 cm in diameter. Capps (1916, p. 299) continues: "In the Glacier Creek area--the white gravels are not overlain by coal bearing beds, but by a thick deposit of tilted oxidized gravels."

Oxidized gravels similar to those described by Capps (1916) can be found in several localities east of Chitsia Creek in the northern Kantishna Hills. The exposures examined during this study were mainly in the eastern portion of the study area. These localities contain poorly sorted, subangular to subrounded channel gravels with clasts up to 10 cm in diameter alternating with bleached sand, and silt partings. Measured attitudes indicate northward tilts of up to 17°.

Thirty and eighteen meter thick sections of Tertiary sediments were measured at the junction of Moonlight Creek and 2 km upstream from the mouth of Gorge Creek respectively. Both Ts sections were capped by a quartz breccia which is overlain by wind blown silts and sand; the bases were not exposed. At the Moonlight Creek Section (fig. 45) five distinctive fluvial channels interbedded with sands and silts reflect an anastamosing, braided, fluvial-floodplain environment. Pebble counts from the Moonlight and Gorge Creek channels show the following composition:

Moonlight Creek Section	Gorge Creek Section
(1 channel pebble count) in percent	(2 channel pebble counts) averaged in percent
White quartz 50	(vein) quartz 26
Polymetamorphic schist 45	(meta) quartzite 20,
Slate 4	mica schist 25
Felsic intrusive 1	dark gray phyllite 15
	metachert 6
	garnet (?) 4
	undetermined opaques 4

Both indicate a strong metagenic clast provenance of local origin.

Although not found in place, lignitic to sub-bitominous coal float was observed by the author in the active flood plains of Glacier and Caribou Creeks and the exploratory churn drilling project previously described sank through thin coal partings in the "white gravels" there. The upper Moose-Stoney Creek area contains at least one outcrop of lignitic coal that approaches 4 meters in thickness (Moffit, 1933). In the 1920's, this coal was transported to Mt. Eielson where it was consumed for exploratory prospecting ventures.

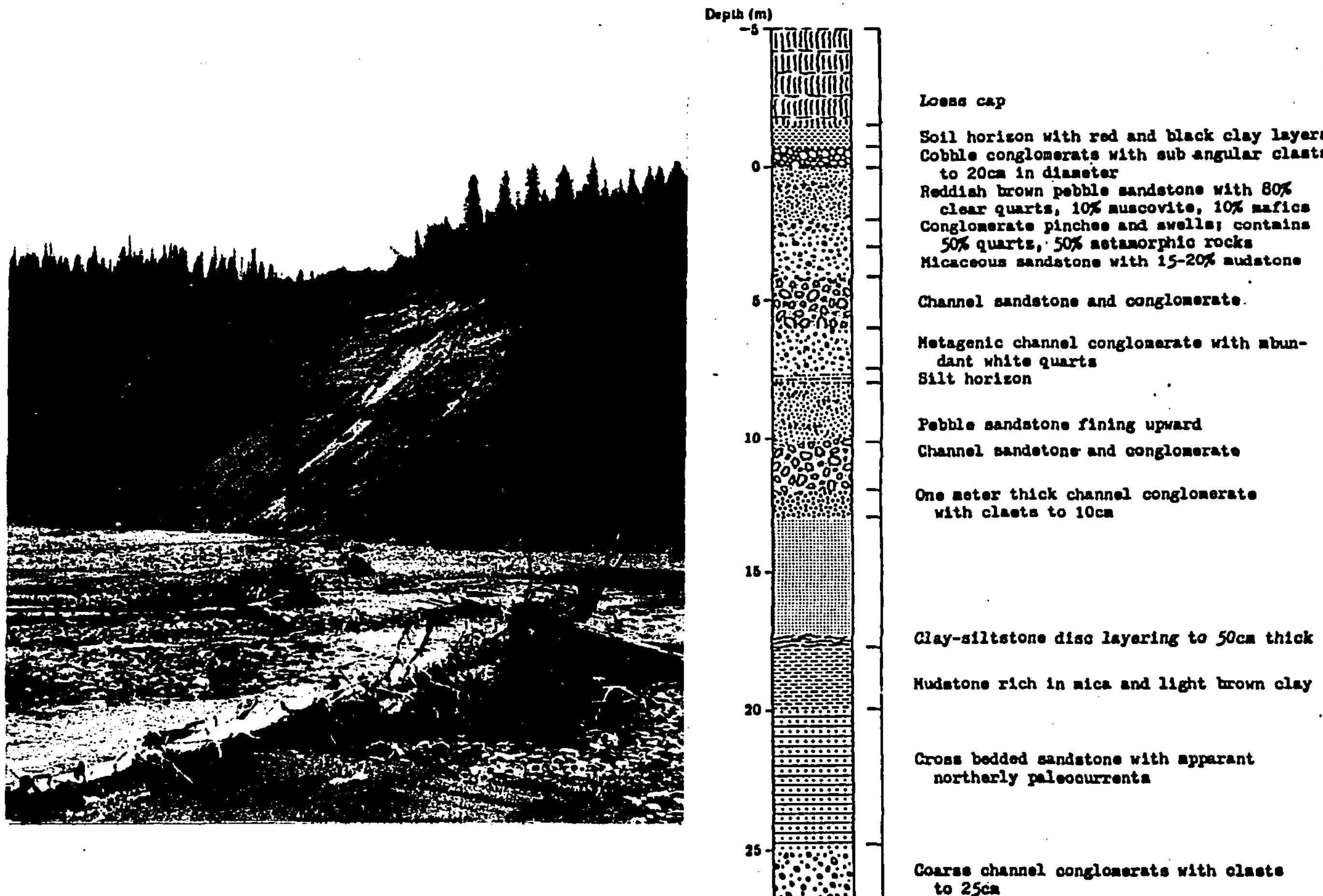


Figure 45. Moonlight Creek Tertiary sedimentry rock exposure showing measured section.

Age and correlation

No fossils were found during this study. Capps (1916, p. 298-299) believes that the "white gravels" on Glacier Creek are correlative with the basal portion of the Tertiary Coal bearing group at Healy. He based this conclusion on the similarities of quartz rich gravels at the base of the Healy and Glacier Creek sections which presumably are derived from a deeply weathered land mass of low relief. He further suggests that the main Coal Bearing Group was stripped off of these basal gravels prior to Pleistocene terrace formation. However, northerly paleocurrent indicators at the Gorge Creek exposure suggests a correlation with the Nenana Gravel of Pliocene age (Wahrhaftig, 1968). Because of the lack of definitive faunal or radiometric age control, the Ts units are regarded as Late Miocene to Pliocene in age.

Quaternary Depoosits

Introduction

Quaternary units of the Kantishna Hills represent a complex history of glacial and non-glacial deposition of unconsolidated sediments that include at least two ages of drift, terrace alluvium of several ages, alluvial fans, landslide debris, modern day stream alluvium, and undifferentiated swamp, eolian and fluvial deposits. The present Quaternary study has been reconnaissance in nature and the details of the stratigraphy of the deposits is much more complex than is shown on plate 1. Photogeologic and ground reconnaissance constituted the principal methods of study.

Glacial till (Qd)

At least two glacial advances have left till in the valleys of Moose, Eldorado, Moonlight, Canyon, Little Caribou, and Spruce Creeks and the Clearwater Fork. The oldest advance (Qd-1) left rounded hills and depressions composed of gravel, sand, silt and organic deposits. This material, for the most part, represents isolated remnants of unsorted diamicton perched at elevations of 2,600-3,000 feet (795-955 m) on the northern slopes of upper Moose and Myrtle Creek valleys. Large glacial erratics up to 3 m in diameter are perched at an elevation of 2,800 feet on the bedrock ridge 5 km south of Camp Denali and on the divide between Friday and Eureka Creeks. Till (Qd-1) has been modified by slope processes and dissected by stream runoff and mass wasting. Rounded kettles are infilled with organic much and number 5-10 per square km. The relict distribution of the Qd-1 unit suggests that a proto-Muldrow glacier advanced over the tops of the low hills both east and west of Wonder Lake and filled the main valley of Moose Creek and tributaries with ice. Difluent tongues lapped over into the Clearwater Fork of the Toklat River and down Moose Creek beyond the mouth of Eureka and Eldorado Creeks.

Younger till deposits (Qd-2) are mainly exposed at the southern boundary of the study area south of the Moose Creek drainage where they form a classic terminal moraine damming up 4 km long Wonder Lake. The till consists mainly of unconsolidated sand, silt and angular to subrounded intrusive, volcanic, and conglomerate clasts derived from the Alaska Range to the south. The topography of this till is relatively unmodified with little or no evidence of dissection by stream runoff except near major stream channels. Steep morainal fronts exist at the terminus near Wonder Lake and to the west at the headwaters of Eldorado Creek. Kettles in the Qd-2 unit average 25-35 km^2.

Poorly exposed till (Qd) consisting of unsorted diamicton and inactive rock glaciers occur as isolated patches at the heads of Canyon, Little Caribou, and Caribou Creeks in the central Kantishna Hills (fig. 46). No exotic material is recognized in these till deposits. The till has been extensively modified by stream erosion and most of the original deposits have probably been eroded away due to rapid uplift in the area. Associated evidence of this glaciation are classic U-shaped valley configurations at the headwaters of streams. Till distribution and valley morphology suggests that at least six small valley glaciers advanced several kilometers radially outward from high portions of the Kantishna Hills.

Age. No definitive radiometric or chronological age control is known for the glacial deposits of the study area. The oldest drift (Qd-1) probably correlates with the "oldest moraines" described by Reed (1961, p. 22) which Péwé (1975) correlates with the early Wisconsinan Healy Glaciation. Terminal moraines and other land forms of the younger till (Qd-2) near Wonder Lake are late Wisconsinan features probably equivalent in age to the Riley Creek Glaciation near Healy (Wahrhaftig, 1958).

The age of till in the central Kantishna Hills is uncertain. The modified morphology of the till may indicate an Early(?) Wisconsinan age. However, rapid uplfit has occurred in the Kantishna Hills which probably accelerated erosional processes. Valley morphology and the

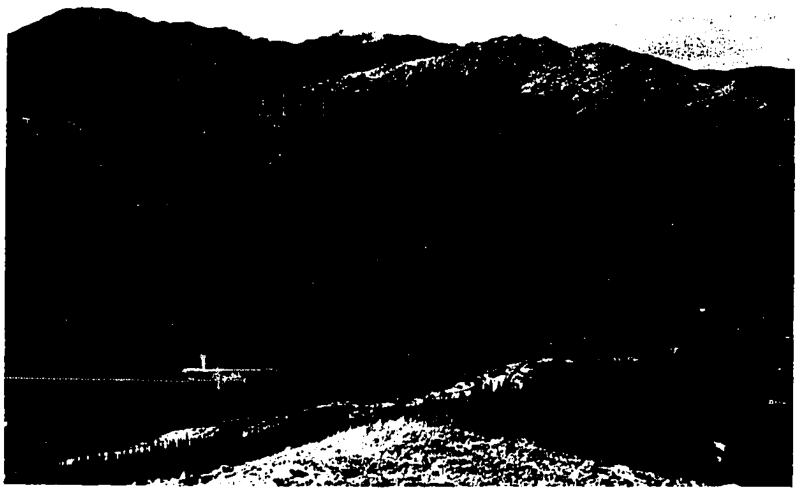


Figure 46. Till deposits on lower Canyon Creek, near junction with North Fork.

presence of inactive rock glaciers would suggest a late Wisconsinan age for these deposits.

Terrace alluvium (Qb)

Glacial advances and associated stream aggradation have left poorly stratified glacio-fluvial outwash deposits that form striking, near-horizontal terraces on Moose, Glacier, and Stoney Creeks and the Clearwater Fork. These terraces are without exception covered by grass-tussuck vegetation mats and thin wetlands or swamp deposits, but are fairly well exposed in stream cutbanks. The Qb distribution shown on plate 1 is a product of aerial photographic interpretation augmented by the examination of cutbanks in stream drainages of the study area.

At least four levels of terrace alluvium have formed on Moose Creek while three have been recognized on the Clearwater Fork and on Stoney Creek. The difference in elevation between terrace levels reflects uplift between glacio-fluvial cycles.

The highest and presumably oldest terrace near Stampede airstrip is roughly 500 feet (160 m) above the Clearwater Fork floodplain. The same terrace is up to 350 feet (110 m) above the modern floodplain of Myrtle Creek 20 km to the south. In both areas, the terrace alluvium is extensively modified by stream dissection and terraces are largely stripped of gravel. Younger terraces have been modified to varying degrees by alluvial fans, landslides and modern stream downcutting. A northward tilt of about 40 feet/mile (8 m/km) was observed for the highest terrace surface near Stampede, but lower terraces elsewhere approximate the present stream gradient in respective drainages.

The material in all terrace deposits generally consists of poorly sorted, rounded, sand to cobble sized clasts of greenstone, felsic intrusive, indurated pebble conglomerate, minor limestone, and metamorphic rocks that indicates a distal Alaska Range provenance but could include clasts of local derivation. The deposits are almost identical to those one encounters on modern, braided glacial stream valleys such as those in the Alaska Range today.

Age. The terrace alluvium in the study area reflects outwash gravel deposition in response to Pleistocene glacial advances of several ages. Glacial till (Qd_1) of the Healy(?) Glaciation overlies the highest level terrace at the headwaters of Myrtle Creek. Wahrhaftig (1958, p. 36-45) describes similar terrace sequences near Healy as outwash deposits associated with four distinctive glacial advances. High level terrace deposits near Stampede and on Myrtle Creek may be outwash from the Dry Creek (Illinoian) Glaciation. Mid-level terraces at Stampede and Stoney Creeks are probably Healy Glaciation outwash deposits while the shallow low level terrace alluvium on Moose Creek likely represents Riley Creek outwash deposited during advances and readvances of late Wisconsinan age.

Landslide debris (Qsl)

Large scale mass movement has resulted in landslide and debris flow deposits in rugged 'V-shaped' canyon walls in the south and east-central Kantishna Hills. One large mass 1/2 km wide about 2 km above the mouth of Eureka Creek blocked the stream causing a significant stream deflection. A similar but smaller slide blocked and deflected Little Moose Creek.

It appears that in both areas, dip slip movement along foliation planes parallel to the steep hill slopes contributed to the rock failures.

Early miners encountered debris flows in the creek valleys during the ealry years. According to Capps (1916, p. 300), "in many valleys, flows of detritus containing muck, soil, and coarse talus have moved down the valley sides and out upon the stream gravels and have buried the paystreak many feet deep. In such places, the richness of the gold concentration must determine whether or not excavation of the 'slide' is justified." Debris slides are present on Friday, Caribou, and Glacier Creeks. The author observed several rock-vegetation-debris flows sliding into Caribou Creek 3 km upstream from the mouth of Last Chance Creek during July of 1975 shortly after a hard rainfall. One flow contained at least 200 cubic m of material; the total amount of debris transported in Caribou Creek after the rainfall is roughly estimated at 1,000 cubic m. Such a phenomenon is probably responsible for burial of placer paystreaks noted by earlier workers.

Landslide and debris deposits in the study area have been forming since the last recession of Pleistocene Glaciation. Rapid uplift, retreat of ice in some areas, zones of water saturation and structural incompetance have all contributed to mass failure that moved colluvium downslope into steep 'V-shaped' valleys.

Alluvial Fan Deposits (Qaf)

Alluvial fan deposits composed of unsorted, rounded gravels and sand form thick aprons up to 3 km across and 30 m thick at the confluence of tributaries and mainstreams throughout the Kantishna Hills.

Material from these areas is derived from reworked terrace alluvium (Qb) originating mainly from the Alaska Range, but smaller fans within the central Kantishna Hills contain clasts entirely of local derivation.

The fan deposits on Upper Moose Creek and Clearwater Fork began forming shortly after Qd-1 drift deposits (Healy Glaciation) were laid down, but are relatively dormant today; extensive forest vegetation covers all but the creek level of the fans.

Small gravel fans and aprons on Canyon, Caribou, Moonlight, and North Fork Creeks are in the process of formation today and are a result of downcutting and short term hydraulic events. These fans are largely unvegetated with anastomosing stream channels periodically covering the entire surface with coarse gravel and sand.

Stream Alluvium (Qal)

Streams and rivers are depositing gravel, sand, and silts on modern flood plains. Much of this alluvium (Qal) contains well round clasts of either local or distal origin depending on the stream drainage and source areas. Upland streams contain clasts of local origin only, but those drainages that head in areas containing outwash and glacial drift contain a mixture of clasts from local and distal provenance.

Placer Mine Tailings (Qht)

Since the early part of the Twentieth century, miners have processed gold and heavy mineral bearing gravels through washing or sluicing plants and selectively stacked the gravel-sand "tailings" along the banks of streams in the southern and east central Kantishna Hills. Where of mappable size such as those on Caribou Creek, the tailings appear on plate 1 as the Qht unit. They are composed of the same material as the stream alluvium (Qal). Qht often includes angular blocks of bedrock that have been ripped up along with the stream gravels during gold mining.

Undifferentiated Quaternary Depostis (Qu)

Undifferentiated Quaternary deposits cover large portions of the study area. Qu includes vegetated hills and plains, suspected gravel terraces, swamp deposits, ice-rich eolian silt pocked with thermokarst pits, loess covered areas, and sand dune complexes. North and east of lower Moose Creek Canyon and west of Flume Creek, Qu is composed of meandering stream deposits, elliptical oxbow lakes, and small thaw pits up to 100 m in diameter. South of Marten Hill, tussock tundra and meandering stream deposits comprise the Qu unit; the tundra is possibly underlain by thin terrace gravel, glacial drift, or remnants of Tertiary sedimentary rocks. The Qu unit in the upper Moose Creek and Bearpaw River drainages reflect lack of bedrock control.

STRUCTURE

Introduction

Deformation observed in the study area reflects a complex history of at least three periods of regional metamorphism, penetrative deformation and brittle fracturing. Structural data has been summarized on six equal area (Schmidt) stereographic projections (figs. 47-53). Terminology used in the following discussion is based on methods described by Cloos (1946).

Foliation or Rock Cleavage

Foliation occurs in units of the Birch Creek Schist, the Spruce Creek Sequence, the Keevy Peak formation, and the Totatlanika Schist and is primarily defined by the parallel orientation of mica flakes. In the latter two, foliation usually parallels compositional banding of relict igneous and sedimentary protoliths (S_1) but both S_2 and S_3 surfaces are well developed in units of the Birch Creek Schist and Spruce Creek Sequence. Surfaces of differing age are not differentiated on the geologic map (pl. 1). A lower hemisphere equal area net of 421 poles to foliation and cleavage in Birch Creek Schist units show several populations of foliation: a major population striking N50E dipping both to the NW and SE and a secondary population that strikes N40 and 55W and dipping to the southwest (fig. 47). The northeasterly striking foliations usually parallel transposed compositional banding (S_1) on adjacent limbs of regional fold structures but some northwesterly foliations are believed to represent cleavage that transects compositional banding. The best

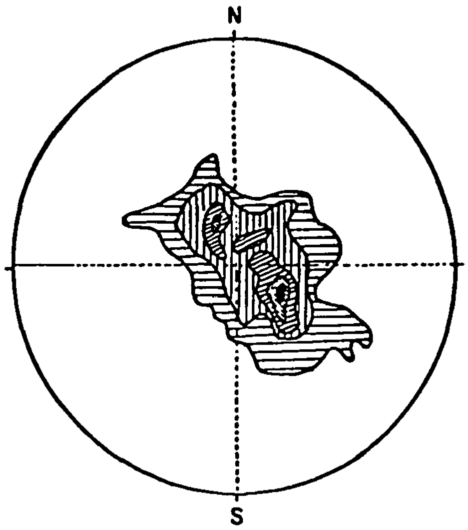


Figure 47. Lower hemisphere, equal-area net (Schmidt Net) of 421 poles to foliation in Birch Creek Schist. Contour intervals at 2, 4, 6, 8, and 10 percent per 1 percent area.

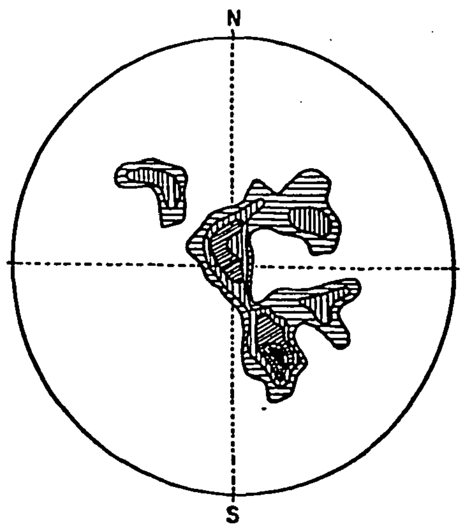


Figure 48. Lower hemisphere, equal-area net (Schmidt Net) of 71 poles to foliation in Spruce Creek Sequence. Contour intervals at 2, 4, 6, 8, and 10 percent per 1 percent area.

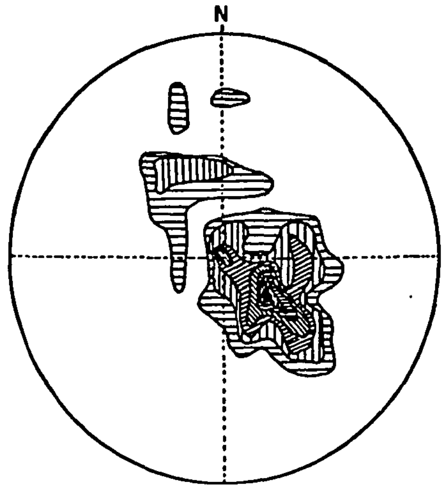


Figure 49. Lower hemisphere, equal-area net (Schmidt Net) of 104 poles to foliation in Keevy Peak Formation and Totatlanika Schist. Contour intervals at 2, 4, 6, 8, 10, 12 and 14 percent per 1 percent area.

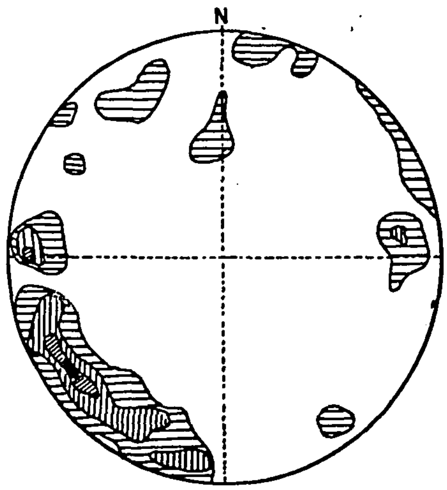


Figure 50. Lower hemisphere, equal-area net (Schmidt Net) of 98 crenulations and kink bands (S_2, S_3) from metamorphic rocks in Kantishna Hills. Contour intervals at 2, 4, 6, and 8 percent per 1 percent area.

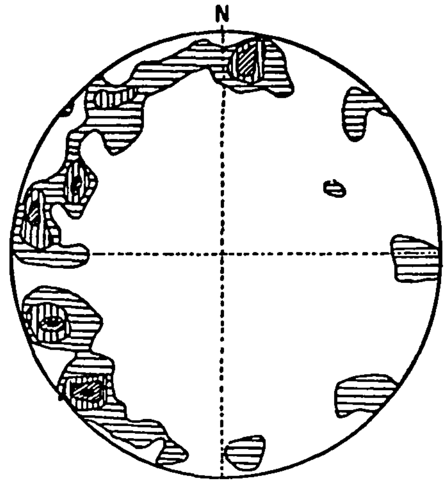


Figure 51. Lower hemisphere, equal-area net of 89 isoclinal fold plunges (f_1, f_2) in Birch Creek Schist and Spruce Creek Sequence. Contour intervals at 2, 4, 6, and 8 percent per 1 percent area.

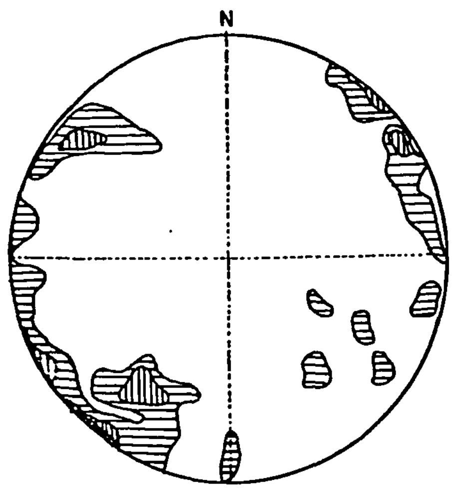


Figure 52. Lower hemisphere, equal-area net (Schmidt Net) of 92 poles to joints from metamorphic rocks, Kantishna Hills. Contour intervals at 2, 4, and 6 percent per 1 percent area.

example of the latter case can be found at the headwaters of Crooked Creek, where S_2 surfaces pervasively cut compositional banding.

The Spruce Creek Sequence contains a similar distribution of poles to foliation and cleavage (fig. 48) indicating at least two episodes of penetrative deformation as does the Birch Creek Schist. The maximum foliation-cleavage populations strikes N50-65E and dip to the NW and SE with secondary orientations striking N30-40E and N35-40W -- both dipping to the south. Foliation in the Totatlanika Schist and Keevy Peak Formation (fig. 49) display a strong N45E strike dipping to the northeast with a secondary southeasterly dip reflecting the faulted limbs of regional fold structures. A minor northwest trending S_2(?) cleavage is pervasive in the lower Keevy Peak Formation Pks unit south of Chitsia Creek.

Crenulations and Kink Bands

Crenulations and kinking of foliation surfaces is exhibited in all metamorphic rocks of the study area but is best developed in the Birch Creek Schist, where distinctive plunge populations exist. The largest population (fig. 50) steeply plunges S55W10°-20° while a subordinate group oscillates on either side of the east-west axes dipping up to 20°. Both populations are believed to represent an f_2 folding episode. The S55W 10-20° plunge is almost identical to results reported by Gilbert and Redman (1977) for f_2 structures in Precambrian-Paleozoic polymetamorphic rocks in the Wyoming Hills. Diffuse crenulations and kink bands that plunge N65W are believed to be associated with an early f_1 deformation. Other diffuse northwest plunging kink bands and crenulations cannot be clearly related to f_1 and f_2 events and probably reflect the range of axial wobble during multiple deformation.

Isoclinal Folds

The earliest fold structures preserved in the metamorphic units are f_1 isoclinal folds with axes shallowly plunging N60-70W (fig. 51). These northwest plunging isoclinal folds are overturned to the northeast and are believed to reflect the earliest recognizable fold deformation (fig. 53); a later shallowly plunging set of S60W isoclinal folds are probably associated with later f_2 folding.

Joint Sets

Conjugate joints have fractured competent rocks during late stages of deformation in the study area. An equal area net of 92 poles to foliation (fig. 52) demonstrates the existence of a N25-45W trending high angle joint system conjugate to a more diffuse secondary northeast trending high angle set. Quartz has been injected into the northwest trending joints in metafelsites (Mtr) near Chitsia Mountain. This deformation may indicate hydraulic fracturing associated with f_3 folding.

Large Scale Folds

Larger scale folds related to f_1 and f_2 and f_3 events have amplitudes measured in the hundreds to thousands of meters and include both open and isoclinal forms. Upright open to isoclinal northeast trending anti-clines and synclines generated by f_2 and f_3 folding are the dominant structural elements in the Kantishna Hills. An equal area projection of 42 fold axes (fig. 54) reflects the dominant northeasterly and

Figure 53. Isoclinally folded (f_1) quartzite, pCs unit, Crooked Creek area.

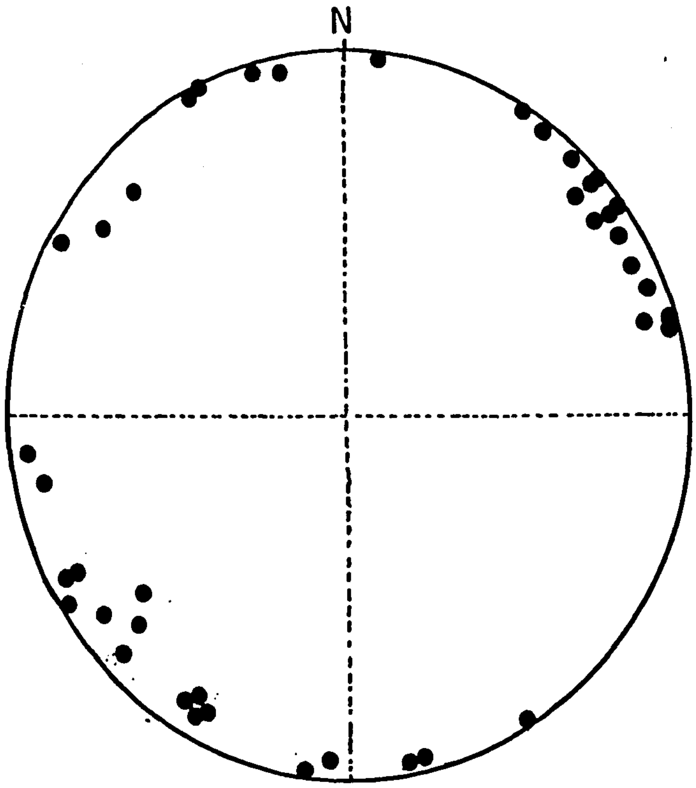


Figure 54. Plunges of fold axes of 42 synclines and anticlines, Kantishna Hills.

secondary northwesterly trends of folds in the study area. The previously discussed equal area projection of poles to foliation also reflect the two trends with the dominant northeasterly foliations dipping both northwest and southwest (limbs of the folds) with a slight assymetry to the northwest. Most of the folds have amplitudes of several hundred meters and extend laterally several kilometers, but one large fold, the Kantishna Anticline, has an amplitude of up to 4 kilometers and extends 40 km from Eldorado Creek northeastward to the headwaters of Moonlight Creek. The broad northwest trending anticlines and synclines (f_3) are superimposed on earlier upright northeast trending isoclinal folds (f_2) that have high (5:1) limb-amplitude ratios. The f_3 warping represents the last stage of fold deformation recognized in the study area. Northwest trending open folds with amplitudes of tens to hundreds of meters near Moonlight and Little Moose Creeks are enveloped in the dominant northeast trending structural trends and probably represent f_1 deformation.

Thrust Faults

Tectonic contacts between several metamorphic terranes in the study area are thrust faults. The best examples occur near Wickersham Dome, at the divide between Crevice and Spruce Creeks, and in the Chitsia Creek area. On a road cut south of Wickersham Dome, a thrust fault is marked by a three meter wide zone of sheared talcose muscovite schist. Exploration tunneling and trenching of this same zone near the divide between Eureka and Friday Creek intersected a low angle shear zone 10 m wide dipping 35° -- mapped as the Birch Creek Schist-Spruce Creek Sequence contact. A low angle shear zone wholly within Birch Creek Schist in road cuts west of Eureka Creek dips 22-33° and is infilled with quartz-carbonate-sulfide vein material (prospect 21, pl. 1). Low angle shear zones cut the Last Chance antimony prospect and Banjo-Jupiter Mars lode system (prospect 63, 35, 36; pl. 1).

Locally, thrust faults separate the Keevy Peak Formation from the Totatlanika Schist in the northern Kantishna Hills. These faults are believed to be activated along zones of weakness in the incompetent Keevy Peak Formation slates and phyllites.

Most of the thrust faults are believed to be synkinematic with f_2 penetrative deformation and folding. The authors suggest that rotated microtextures observed in thin sections of polymetamorphic rocks of the Birch Creek Schist may be associated with this penetrative deformation.

High Angle Faults

Most high angle faults trend northeast parallel to structural grain in the Kantishna uplands. The Crooked Creek Fault extends 55 km from Fault Creek southwest to Rock and Caribou Creeks, where its continuation is uncertain. Near Fault Creek, this fault juxtaposes a large wedge of Keevy Peak Formation on the east with basement Birch Creek Schist on the west. The fault near Crooked Creek truncates an amphibolite rich terrain to the northwest from graphitic rich schist to the southeast--both lithologic units of the Birch Creek Schist. The nature of offset along the Crooked Creek Fault is uncertain. It seems plausible that amphibolites near Crooked Creek are roughly equivalent to those mapped in the Quigley Ridge-Spruce Creek area which would imply a speculative right lateral offset of approximately 20 km. Another large high angle fault, possible a splay of the Crooked Creek Fault, trends southwesterly through low hills south of Flume Creek and forms an abrupt topographic boundary between the Kantishna upland and Quaternary filled lowlands to the north. Low saddles south of Flume Creek contain water filled depressions that could be sag ponds along a dilatant zone of recent faulting; however, no relative sense of movement is known.

Keevy Peak Formation and Spruce Creek Sequence units north of Canyon Creek, near Stampede, and along Crooked Creek appear to be bounded on all sides by high angle faults. This faulting pattern is similar to block faulting described by Gilbert and Redman (1977) in the Wyoming Hills.

A pervasive set of northwest trending faults and a few north-south trending faults cut conjugate to the main northeasterly structural grain in the Kantishna upland. Most of these faults displace bedrock units vertically and laterally only a few tens to hundreds of meters but the Moose Creek fault may have a left lateral offset of 2 1/2 km (Morrison, 1964, p. 74). In the Eureka-Spruce Creek area, where northwest trending faults are best exposed, both left and right lateral offsets of a few hundred meters were recognized. One possible active fault 4 km southwest of VABM Antim strikes N54W, contains slump features, sag(?) ponds and is marked by a furrowed trench along a high ridge line. Most northwest trending faults are believed to be Late Tertiary to Quaternary in age.

Structural Summary

Structural evidence including primary and secondary fold structures, foliation and rock cleavage, and low angle faults indicate that at least two major episodes of pre-Cenozoic regional penetrative deformation affected the metamorphic rocks in the Kantishna Hills. Late Cenozoic high angle faults and uplift reflect a period of tensional tectonism in the form of block faulting and graben formation. The following summarizes the deformational events:

1. Multiple penetrative deformation resulted in the formation of open to upright, northwest trending f_1 isoclinal folds and development of foliation (S_1) usually parallel to original sedimentary and igneous layering. Evidence for this deformation is preserved in the Birch Creek Schist and Spruce Creek Sequence but absent in the Totatlanika Schist and Keevy Peak Formation. This event probably correlates with pre-Jurassic (Bundtzen and Turner, 1979), perhaps pre-Devonian (Sherwood, 1980) regional metamorphism which in the Birch Creek Schist, reached the amphibolite metamorphic facies in the study area.
2. Compressional deformation result in the formation of upright, north east trending isoclinal folds (f_2) and synkinematic thrust faulting; S_2 cleavage (figs. 55, 56) developed during this time. This deformation may correlate with mid-Cretaceous metamorphic event that produced greenschist facies mineral assemblages present in the Birch Creek Schist, Spruce Creek Sequence, and Totatlanika Schist. Compressional stress from this deformation is probably responsible for rotated microtextures (i.e., garnet snowballs) observed in polymetamorphic rocks. Structurally, higher portions of the metamoprhic section (Totatlanika Schist) experienced milder deformation and accompanying

Figure 55. S_2 cleavage development, Keevy Peak Formation, Chitsia Mountain area.

Figure 56. Joints infilled with quartz, Mtr unit, Totatlanika Schist, Chitsia Mountain massif.

slightly lower grade regional metamorphism. Thrust faults juxtaposed the older Birch Creek Schist over the younger(?) Spruce Creek Sequence.

3. A last phase of folding (f_3) warped the structural grain into broad, open synclines and anticlines during late Cretaceous or early Tertiary time. High angle joints and fractures are infilled by quartz during dewatering phases of Cretaceous regional metamorphism (fig. 56). True structural domes such as Busia Mtn., Wickersham Dome, and rounded knobs near Stampede formed when these warps intersected previous f_1 and f_2 fold axes, resulting in a classic "egg crate" or potato sack fold style. The f_3 warping locally folded thrust faults associated with f_2 compression.
4. The initiation of high angle block faulting; and high angle fracturing along northeast trending faults parallel to regional structural grain took place in Cenozoic time. This fracturing event was responsible for intrusion of dikes in the south-central Kantishna Hills. The block faulting also produced structural lows that later contributed to the development of the Crooked Creek erosion surface and sites of Tertiary sedimentary rock deposition. The block faulting episode probably continued through late Tertiary time.
5. Northwest trending faulting took place in Late Tertiary to Recent Time. A few northwest trending faults are older features associated with last stages of regional penetrative deformation but most are fairly recent features offsetting the northeasterly structural grain. They are believed to reflect the Late Tertiary and Quaternary uplift of the Kantishna uplands, still active today.

Gilbert and Redman (1977) have postulated a similar structural history to that proposed here in the Wyoming Hills east of the Kantishna Hills. The structural grain of Kantishna country is observed today in the present trend and shape of the uplands, the stream drainages, and valley morphology. The modified trellis style of stream patterns reflects the northeast structural grain and the distribution of Tertiary sedimentary basins. Features such as the Flume Creek Fault form topographic breaks between uplands and lowlands.

ECONOMIC GEOLOGY

Introduction

The Kantishna Mining District contains complex polysulfide-sulfosalt vein mineralization, placer gold deposits, pyrite-antimony lodes, metalliferous skarns, and stratiform base metal occurrences. Geologic summaries and 413 assays of 87 mineral deposits in the study area are provided in Tables 9 and 10.

A summary of mining history has been published (Bundtzen, 1978), only portions of which are presented here. Placer gold was first discovered in Chitsia Creek of northern Kantishna Hills by Judge James Wickersham while in route to his 1903 unsuccessful bid to climb Mount McKinley or Denali, as it is now known. This initial discovery prompted others to search for gold in the foothills of the Alaska Range. In 1904 Joe Dalton located placer deposits on Crooked Creek in the central Kantishna Hills and in 1905, coarse gold was discovered at about the same time by Dalton and Joe Quigley in Eureka and Glacier Creeks respectively. The 1905 discoveries stimulated a brief but colorful gold rush that involved several thousand individuals; however, it was soon learned that pay in the creeks, although locally rich, was limited to shallow gravel deposits in confined canyons. By 1906 only a handful of the original stampeders remained to work the gold placers. Total production of gold from deposits on Eureka, Glacier, Caribou, Friday, Moose, Glenn, Spruce, Little Moose, Stampede, and Crooked is estimated at 60,000 ounces through 1980.

The immediate discovery of galena, stibnite, and other sulfide cobbles caught in the sluice box riffles prompted a successful search for hardrock mineral deposits. The high price of antimony during the Russo-Japanese War of 1905 led Joe Quigley to mine and ship 12 tons of stibnite ore from the Last Chance lode on Caribou Creek (pros. 63b, pl. 1); thus began the development of lode mining in the region. By 1919 numerous mineralized vein-faults containing antimony, silver, lead, zinc, gold, copper, arsenic and tungsten minerals had been located in a 40 km long northeast trending belt extending from Slate Creek to Stampede. Between 1919-1924, development of eight small, high grade silver lodes in the Quigley Ridge area resulted in the shipment of 1435 tons of ore with an average grade of 174 oz/ton silver and 0.5 oz/ton gold. In the late 1930's and early 1940's the Banjo Mine (pros. 35; pl. 1) was mined for gold, silver and minor base metals. Antimony has been commercially recovered from the Last Chance, Slate Creek, Eureka, and Stampede deposits (pros. 35, 1, 17, 73, 74; pl. 1) sporadically largely during high price levels of WWI, WWII, the Korean and Vietnam Wars. Total mineral production from the Kantishna Hills is estimated at 67,000 ounces of gold, 265,000 ounces of silver, approximately 5,000,000 pounds of antimony, and several million pounds of lead and zinc concentrates. Production breakdowns from specific deposits are provided in Tables 11-13.

Vein-Fault Deposits

Vein deposits in the Kantishna Mining District have been discussed in some detail by Wells (1933), Davis (1922), White (1942) Barker (1963) and Hawley (1977). Tables 9 and 10 summarize locations, geology, and available assay information of over 75 vein-faults in the Kantishna study area. Available mine maps and prospect sketches from deposits in the southern portion of the district are provided in plate 3; the reader is referred to Barker (1963) and Hawley (1977) for excellent descriptions of underground and surface development of the Stampede deposits. At the time of the author's visit, most of the underground workings and trenches were caved and inaccessible; thus most of the prospect examinations consisted of dump sampling and observing sporadic surface showings. However, good exposures of sulfide mineralization can be found at the Stampede, Slate Creek, Arkansas, Weiler, Bosart, Bunnell, Gold Dollar, Jupiter-Mars, Last Chance, and Eagles Den deposits (pros. 73, 1, 55, 45a, 41, 42, 4, 26, 36, 63b, and 6; pl. 1).

Mineralogy and paragenesis

According to Wells (1933), gold, arsenopyrite, pyrite, sphalerite, galena, chalcopyrite, tetrahedrite, freibergite, scheelite, siderite, stromeyerite, bouronite, stephanite, stibnite, pyargyrite, cassiterite, and their oxidized products scorodite, melanterite, azurite, malachite, cerussite, stibiconite, and kermesite are metallic minerals that have been reported from vein-faults in the district. However, Wells (1933) expressed some doubt as to the existence of stromeyerite, bouronite, stephanite, and pyrargyrite, because "Paul Hopkins, who reported the presence of stephanite, stromeyerite, and bouronite, said these minerals were not found in sufficiently large crystals for identification, so possibly mixtures of the simple sulfides were taken for these complex minerals." The author completed an examination of 52 polished sections from 32 vein-fault deposits in the district using properties of reflected light, a Vickers microhardness tester, a Leitz reflectivity meter, and augmented by limited X-ray powder camera analysis. This work, summarized in table 14, has confirmed the presence of the questioned stephanite, pyrargyrite, and stromeyreite as well as boulangerite, jamesonite, marcasite, covellite, pyrrhotite, polybasite and its arsenic end-member pearceite. Argyrodite, a rare silver-tin sulfosalt, has been only tentatively identified from the Flourence Lode (pros. 51; pl. 1). Bornite is a common heavy mineral found in pan concentrates on Eldorado Creek presumably derived from nearby lode sources. Gangue minerals identified by the author include siderite, calcite, quartz, and minor to trace amounts of tourmaline, and barite. Large rhodonite boulders are found in the stream gravels of Glenn Creek, but lode sources have never been found. Additional X-ray diffraction analysis of gangue minerals by N. C. Veach (ADGGS) have revealed pharmacosiderite [$KFe_4(AsO_4)_3(OH)_3 \cdot 7H_2O$], pyroxmangite, and dolomite.

As first suggested by Wells (1933), the vein faults can be crudely subdivided into three types on the basis of predominant minerals present: (1) quartz-arsenopyrite-pyrite-(scheelite)-gold veins, (2) galena-sphalerite-tetrahedrite-pyrite-chalcopyrite veins with conspicuous siderite gangue, and (3) stibnite-quartz veins largely free of other sulfides. The Jupiter-Mars, Arkansas, and McGonigill deposits are good examples of the type 1 deposits, while the Weiller and Gold Dollar prospects (fig. 57) illustrate the best exposed type 2 silver rich vein-faults in the district. Stampede, Slate Creek and, Last Chance deposits are all fairly good representatives of the type 3 lodes. Locally, however there is a continuum of sulfide mineral assemblages from one type to another. Scheelite was identified from the Little Annie, Bunnell, Red Top, and Silver Pick lodes which are definitely type 2 vein-faults. Jamesonite

Figure 57. Open cut exposure of Wieler silver lode (prospect 45a, pl. 1) showing relationships between vein and host lithology, and mode of occurrence of sulfide species. G = graphitic schist; LS = limonitically coated sulfides, mainly galena, tetrahedrite, and silver-antimony sulfosalts; Q = quartz, locally brecciated; 1-5 are locations of chip samples reported in table 10.

and stibnite have been identified from the Bunnell and Alpha deposits which are also type 2 vein-faults. The Banjo quartz-arsenopyrite-scheelite-gold deposit (type 1) assimilates larger amounts of base metal sulfides tetrahedrite, galena, and sphalerite, laterally and vertically along strike as indicated in a company report (Morris, 1939), and mill records. The Jupiter-Mars gold-arsenopyrite deposit laterally grades eastward along strike into the Chlorine lode system, a type 2 galena-sphalerite tetrahedrite-pyrite lode. The massive stibnite-quartz lodes appear to be more clearly separated from type 1 and 2 vein-faults.

The mineralogical source of the silver in the bonanza deposits on Quigley Ridge has been debated over the years. Capps (1918), Morrison (1964), and Brooks (1911) have related the silver to high galena content. However, inspection of assay results (tab. 10) suggest that high silver values correlate well with high concentrations of copper, or antimony, or both. Occasionally high silver assays correlate well with lead and arsenic. Comparison of polished sections with assay results show that the highest silver assays are in those samples containing significant amounts of tetrahedrite and the more uncommon silver-antimony sulfosalts. Seraphim (1961) concludes from soil sampling traverses on Quigley Ridge that high copper anomalies associated with tetrahedrite appear to be the best geochemical signature of high grade silver lodes in the district.

The author recognizes 5 periods of gangue and sulfide deposition in most of the polished slabs and thin sections. According to Wells (1933):

> "The minerals in order of their deposition from oldest to youngest are arsenopyrite, pyrite, sphalerite, galena, chalcopyrite, tetrahedrite, jamesonite, and marcasite. Quartz came prior to the sulfide minerals but calcite did not come until after the arsenopyrite and pyrite."

A paragenetic study of both sulfide and gangue minerals from 52 polished sections and 10 thin sections of vein-fault deposits in the district is summarized in table 14. Figure 58a-h illustrates the paragenetic sequences of sulfide species from selected deposits in the district. This work demonstrates that arsenopyrite and pyrite enter the fractures early while the antimony minerals boulangerite, jamesonite, and stibnite are late stage minerals, but the other base metal sulfides--sphalerite, chalcopyrite, galena, and tetrahedrite, have a large sequential range. Sulfosalts of silver and antimony are generally deposited in mid-to-late stage mineralizing events.

At the Fluorence and Gold Dollar deposits (pros. 45, 27; pl. 1) there is early stage sphalerite succeeded by galena, chalcopyrite and tetrahedrite; later sphalerite veins crosscut all sulfides in the specimens. Most of the chalcopyrite in the polished sections from Kantishna vein-faults occurs as exsolution blebs in sphalerite, but at the Bunnell and Galena deposits, it is a major sulfide component of the ores independent of sphalerite. Covellite is ubiquitously late stage and crosscuts most of the sulfide species in all polished sections examined; much of the covellite veining appears to be derived from remobilization of tetrahedrite in the sections.

A nonrigorous study of gangue mineralogy indicates that siderite and quartz are generally deposited during early stages of mineralization followed by barite, calcite, and tourmaline. Cumulative evidence suggests, however, that quartz occurs in all stages of mineralization. The mineral paragenesis presented here generally conforms to the order of mineral progression as proposed by Lindgren (1932) for zoned hydrothermal deposits.

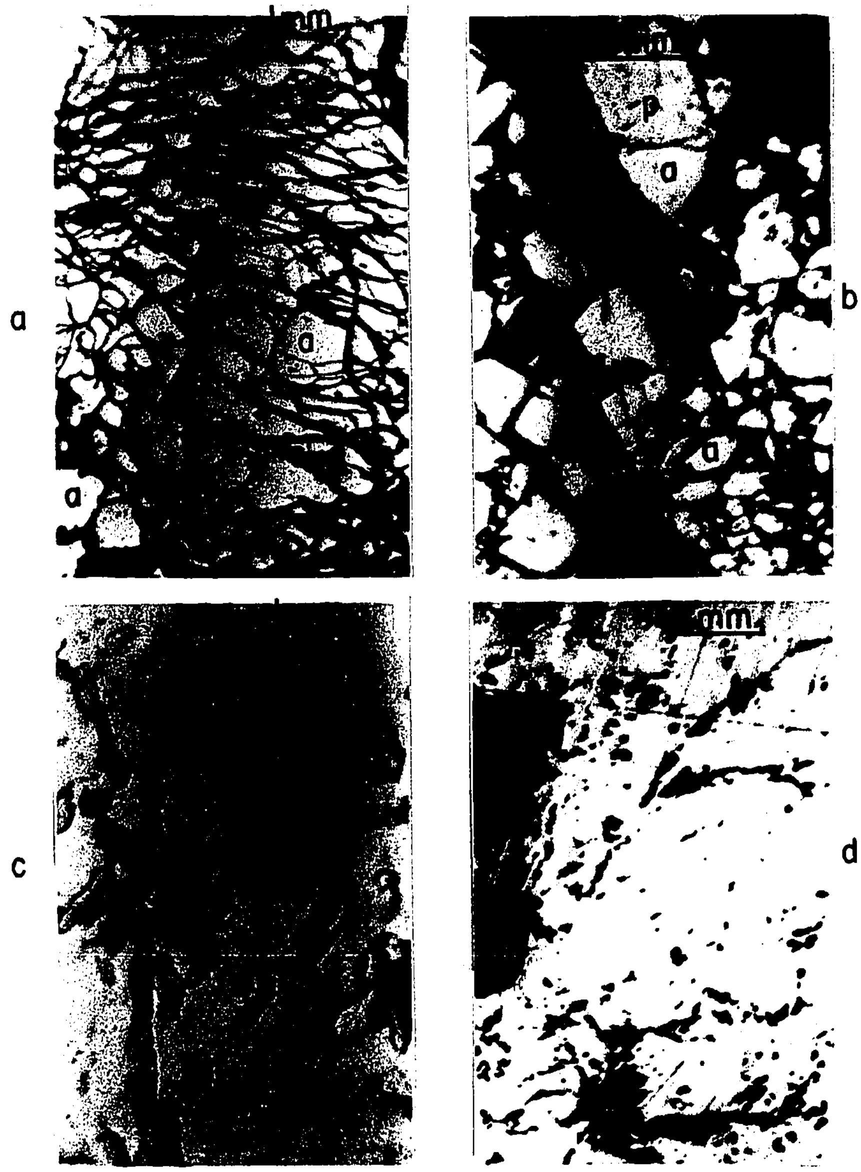


Figure 58a-d. Photomicrographs of polished sections from vein-faults in Kantishna mining district, Alaska. a) Ore from Jupiter-Mars adit showing brecciated arsenopyrite (a) invaded by sphalerite (s). b) Ore from Bunnell Prospect showing pyrite (p) and arsenopyrite (a) invaded by sphalerite (s) with exsolution chalcopyrite. c) Bunnell Prospect sample showing jamesonite (j) forming in cracks within chalcopyrite (c). d) Polytwinned stibnite from Stampede deposit (crossed nicols).

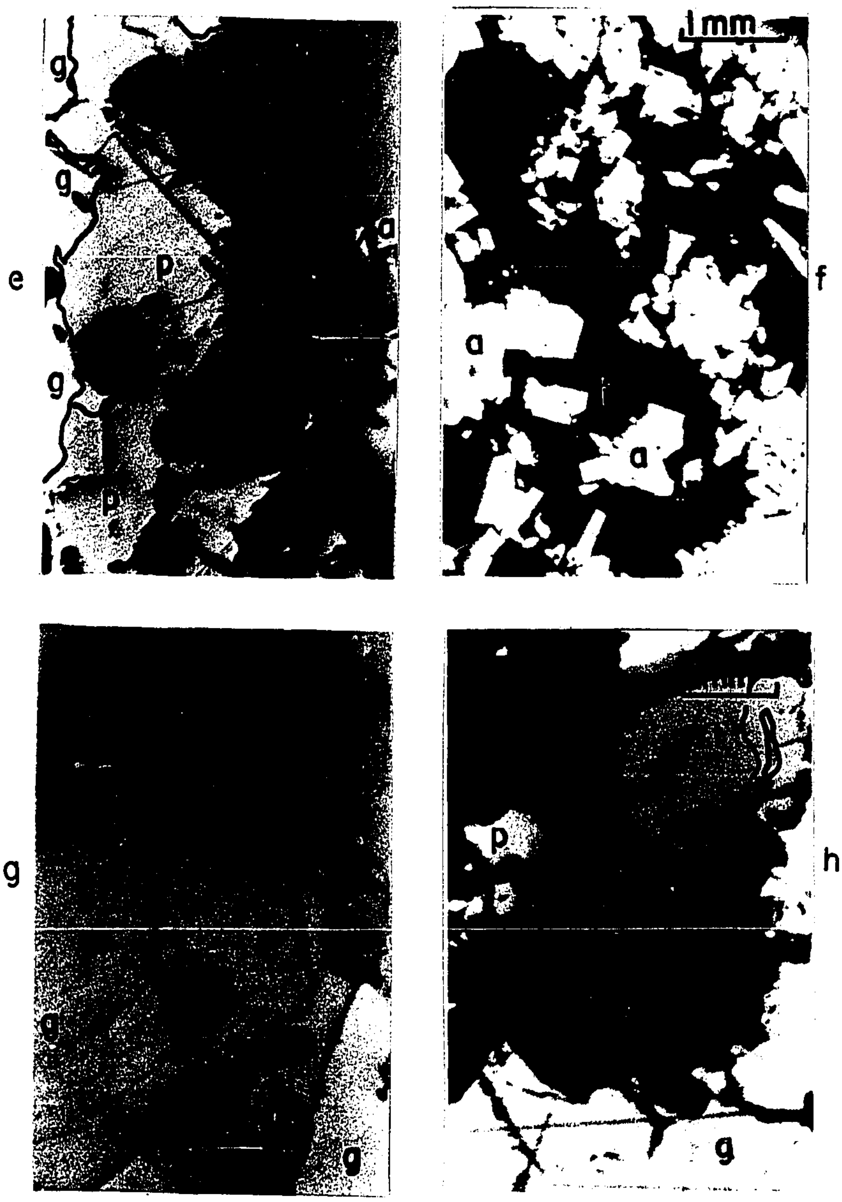


Figure 58e-h. e) Bosart prospect sample showing polybasite (p), galena (g), sphalerite (s), covellite (c), and tetrahedrite (t). f) Arsenopyrite (a), pyrite (p), and sphalerite (s) from Arkansas claim. g) Tetrahedrite (t), pyrite (p), galena (g), and pyrargyrite (y) from Fluorence Lode. h) Sphalerite (s), tetrahedrite (t), and galena (g) from Galena deposit; late covellite veins (c) crosscut all sulfides.

A systematic study of vein-fault wallrock alteration was not attempted in the district. Examination of thin sections from an alteration traverse at the Stampede surface ore body disclosed virtually no wallrock alteration at the immediate footwall and hanging wall of the vein; however this may be a function of the non-reactive nature of the Stampede Quartzite (pCs) host rock. X-ray diffraction analysis by N.C. Veach (ADGGS) reveals sericite and kaolinite alteration in the hanging wall of the Banjo and Jupiter-Mars deposits (pros. 35, 36; pl. 1). Pyritization and propylization of mafic mineralogy is a conspicuous alteration of the porphyry body at the Bunnell Prospect (pros. 4; pl. 1).

Structural controls

The Kantishna vein-faults are largely confined to a semi-continuous 40 km long northeast trending zone extending from Slate Creek to Stampede. Most of the veins are structurally controlled by high angle longitudinal fractures that parallel the assymetrical Kantishna Anticline.

The Kantishna vein-faults strike N30-70E and dip steeply to the southeast; a few dip steeply to the northwest (fig. 59). According to Wells (1933), those veins that dip steeply to the northwest intersect the southeast dipping veins. This crosscutting relationship is believed to have localized the bonanza silver-sulfide lodes on Quigley Ridge (Seraphim, 1961), and some of the large massive stibnite lodes at Stampede (White, 1942; Barker, 1963), thus producing the elongate, kidney shaped ore bodies that were mined. Barker (1963) further suggests that mineralization at Stampede occurred before, during, and after movement along the Stampede Fault as evidenced by both crushed and undeformed ore shoots in

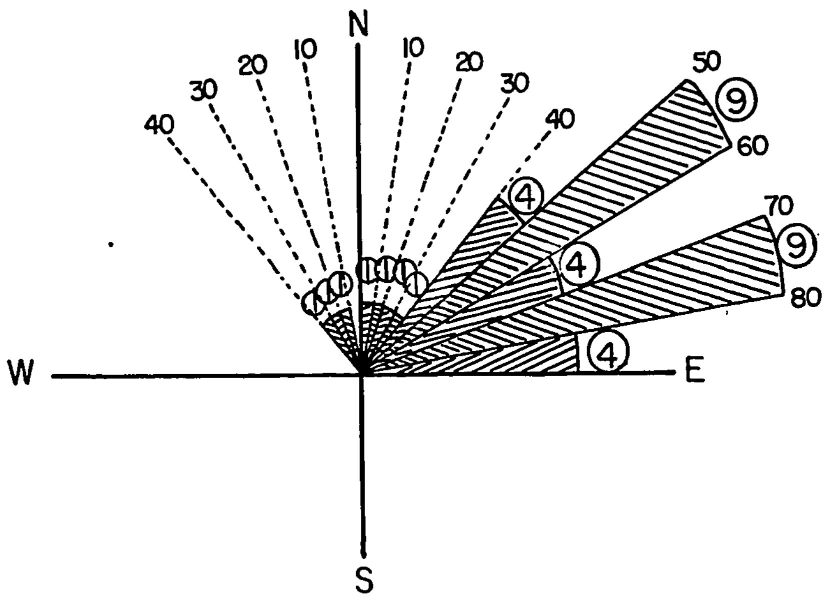


Figure 59. Orientation diagram of Kantishna vein-faults.

the Surface, Emil Winze, and East Mooney ore bodies. Some veins in the district strike N20-40W and appear to cut the older northeast trending veins. These later veins appear to be only weakly mineralized.

Mineralized vein-faults in the study area range in length from less than 30 m to well over 500 m and vary in width from 5 cm to over 9 m. They occur in a variety of lithologies of both the Birch Creek Schist and Spruce Creek Sequence but differ in geometry when cutting through amphibolite, greenschist, quartzite, quartzo-feldspathic schist, marble, or pelitic rocks (fig. 60). In amphibolites or quartzite, the vein-faults consist of thick and relatively continuous breccia or sheeted zones up to 10 m thick as illustrated in the Jupiter Mars, Last Chance, Glenn Ridge, and Stampede deposits. In pelitic rocks, marble, or other lithologies that undergo plastic folding rather than brittle fracturing, the vein-faults are represented by narrow and discontinuous crenulated zones rarely exceeding 0.5 m thick. Vein-faults in these rocks are difficult to trace; they consist of small fractures a few cm wide filled with clay gouge and schist, and are often barren of economic quantities of sulfides. Examples of this type of vein-fault can be found in uneconomic portions of the Little Annie, Arkansas, and Flourence Lodes. In general, competent rocks such as siliceous phyllite and metafelsite of the Spruce Creek Sequence and amphibolite and quartzite of the Birch Creek Schist appear to host the largest and most economically viable sulfide vein-fault deposits. Fryklund (1964) and Boyle (1959) describe similar controls for vein-fault deposits in the Coeur d'Alene and Keno Hill Districts respectively. However Wrennecke (1922) shows that exceptionally high grade silver lodes are hosted in narrow shear zones in graphitic schist

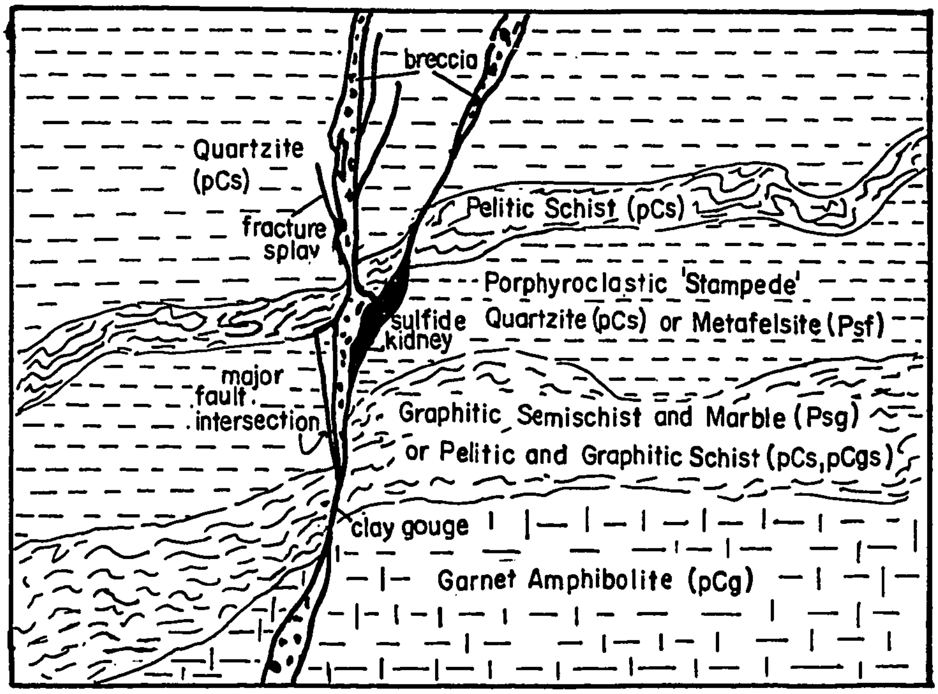


Figure 60. Schematic illustration of vein fault geometry in different lithologic hosts, Kantishna District.

of the Red Top Mine (pl. 3). High grade silver mineralization at the Weiler Prospect (pros. 45a; fig. 57) is hosted in incompetent graphitic phyllite of the Psg unit.

Origin of the vein-faults

Previous workers such as Capps (1918) and Wells (1933) recognized a possible genetic relationship of small hydrothermally altered dikes and plugs of felsic-to-mafic composition (Tf, Tb, Thd; pl. 1) to the vein-faults. These igneous bodies (described previously) are elongated parallel to northeasterly and northwesterly fracture systems and appear to be spatially associated with the Kantishna Anticline. Alkali feldspar bearing quartz porphyry at the Bunnell prospect is undoubtedly related to type 2 mineralization along fractured porphyry-schist contacts and in pendants of schist (pl. 3).

One important line of evidence lies in the preferential emplacement of vein-faults into various lithologies of the Spruce Creek Sequence where approximately 80% of the deposits are located. Only the stibnite-quartz deposits are located conspicuously outside these "ore zone" rocks. Metafelsite and greenschist of the Spruce Creek Sequence contains disseminated to massive sulfide stratiform mineralization containing copper and iron sulfides (described later) which is a suggested source for the metals in the vein-fault system.

No reliable estimates of temperatures of formation are avaialble from the Kantishna vein-faults; no fluid inclusion or accurate geothermometry techniques have been attempted for deposits in the study area. However, utilizing sequential schemes (tab. 15) provided by Krauskopf (1979) and Lindgren (1932), the arsenopyrite-pyrite-scheelite-gold-quartz lodes (type 1) could be classified either as hypothermal or mesothermal deposits. The presence of high temperature gangue minerals tourmaline and apatite in two of these deposits (Arkansas and Jupiter-Mars; loc. 55, 36) suggests the former affiliation. Massive sulfide tetrahedrite-siderite-galena-sphalerite lodes (type 2) contain sulfide species characteristic of both mesothermal and epithermal deposits. According to Oelsner (1961, p. 6) exsolution chalcopyrite in sphalerite, which is common in type 2 lodes on Quigley Ridge, requires a temperature of formation in excess of 250°C. This suggests that type 2 veins in the study area can be classified as sulfides deposited in a mesothermal environment. Massive stibnite-quartz veins such as the Stampede, Last Chance, and Slate Creek deposits probably represent true epithermal deposition of sulfides.

The origin of silver-sulfosalts in precious metal vein-faults such as those in the study area has been debated over the years (Lindgren, 1932, p. 860-868). Replacement textures and elevated grades in near surface mineralization has been cited as evidence for low temperature deposition by descending groundwater during weathering. However, recent work by Vikre (1980) on fluid inclusions in "ruby" silver sulfosalts pyrargyrite, proustite, and polybasite from Tonopah, Nevada shows homogenization temperatures of 230-270°C, suggesting that these minerals precipitated from higher temperature fluids in the mesothermal range and not ground water.

Two isotopic analyses of galena were obtained from vein-faults in the Kantishna District in an attempt to radiometrically date the mineralization (tab. 16). When plotted on $Pb^{208/204}$ - $Pb^{206/204}$ and $Pb^{207/204}$ -

$Pb^{206/204}$ isochrons, the results show multistage lead histories giving apparent futuristic ages for the mineralization (Kanasewitch, 1968; Doe and Stacy, 1974).

A summary of mineralizing event for vein-faults in the study area is postulated as:

(1) Longitudinal fracturing caused by warping of terrain into northeast-trending fold structures.

(2) Emplacement of a heating agent--either mid-Cretaceous greenschist facies of metamorphism or intrusion of porphyry igneous bodies; subsequent outgassing of volatiles and metallic species.

(3) Initial higher temperature arsenopyrite-pyrite-scheelite quartz vein deposition along fractures.

(4) Crosscutting of the earlier fractures and deposition of galena-sphalerite-tetrahedrite-siderite-quartz veins; subsequent cross fracturing and a weaker phase of arsenopyrite-pyrite mineralization.

(5) Low-temperature stibnite-quartz vein deposition along cross cuts, and reintroduction into previous veins. Stibnite-quartz lodes show the widest range of distribution from other vein-faults in the study area.

In the model presented here, hydraulic fracturing of metalliferous host lithologies of the Spruce Creek Sequence may best explain the formation of the Kantishna vein-fault system (fig. 61). Such a hypothesis has its origins in the 'Source Bed Concept', first presented by Knight (1957), in which sulfide ore bodies of this type were originally derived from metalliferous horizons in a volcanic-sedimentary basin and subsequently migrated in varying degrees under the influence of rise in tempera-

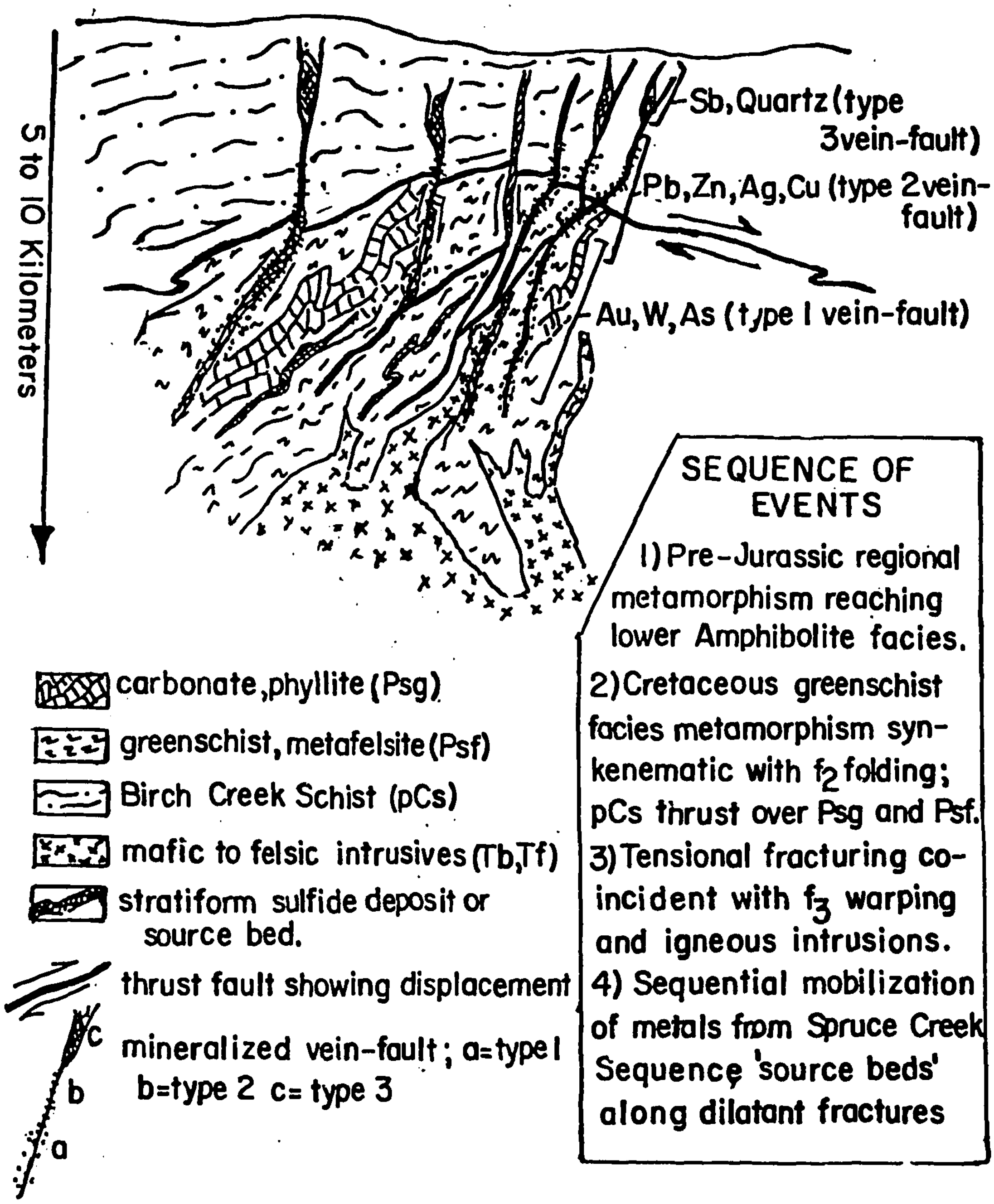


Figure 61. Model of Kantishna vein-fault formation.

ture of the rock environment. The temperature source for such a mechanism in the Kantishna vein-fault system lies either in the mid-Cretaceous greenschist facies event or the Cretaceous-to-Paleocene dike swarm intrusions. The author favors the latter source. Many of the Kantishna vein-faults show evidence of brecciation produced during regional penetrative deformation, and the f_3 deformation that produced the brittle style fractures controlling the ore bodies post dates mid-Cretaceous regional metamorphism. The less likely thermal source involving late stages of Cretaceous greenschist facies metamorphism was considered. Boyle (1979, p. 401) suggests that greenschist facies of metamorphism constitutes the dewatering phase of regional metamorphism which results in a transfer of silica, volatiles, and mineral species in solution into dilitant sites such as faults, or favorable zones of replacement. This mechanism has become a popular theory for explaining the origins of epithermal gold-base metal deposits in Precambrian greenstone belts world-wide. However, the wide temperature range from hypothermal to epithermal zones recognized in sulfide vein deposits of the Kantishna District would not be expected in such a relatively low temperature homogeneous dewatering phase of metamorphism.

A relationship of further exploration significance lies in the alignment of 13 vein-fault deposits that extend from Slate Creek through Alpha and Quigley Ridge, across the north side of Wickersham Dome, and culminating in the Last Chance Lode on Caribou Creek (pl. 1; fig. 62). This 'lode line' coincides with a possible southwestern extension of the Crooked Creek fault system. The author speculates that the intersection of this major fault system with the metalliferous(?) Spruce Creek sequence

Figure 62. Concentration of vein-faults in Quigley-Alpha Ridge area, southern Kantishna District, looking south-southwest.

may be responsible for the high concentrations of vein-faults on Quigley Ridge and Yellow Creek areas.

The following summary may add some insight to the future examination of the Kantishna veins faults.

(1) The "Kantishna antiform" is the regional structure that controls the mineralization and should be explored along strike for more undiscovered sulfide veins. The veins are preferrentially hosted in rocks that have undergone brittle deformation, for example, quartzose phyllite, and metafelsite.

(2) Chlorite phyllites and marble are generally poor hosts of economic sulfide material.

(3) There is no textural evidence for supergene enrichment of the bonanza silver veins, although some enrichment by oxidation may occur at the surface (Wells, 1933; Seraphim, unpub., 1961; this study). This implies that high-grade ore bodies can exist at depth in the vein systems.

(4) Some bonanza silver veins and the large massive stibnite-quartz veins are located where a northwest-dipping vein intersects a southeast-dipping vein. This fracture relationship is a structural guide for ore.

(5) Polybasite, pearceite, stephanite, pyrargyrite, and argentiferous tetrahedrite, are the main silver-bearing minerals. Thus copper, antimony and perhaps arsenic derived from silver-antimony sulfosalts and tetrahedrite could be effective geochemical guides for the exploration of high grade silver lodes.

(6) Siderite is a conspicuous component of high grade ore shoots. Its recognition in the field can be a pathfinder to silver bearing ore bodies.

Stratiform Sulfide Deposits

Introduction

During the course of mineral investigations in the Kantishna Hills, the author and Hawley (1977) have noted the presence of pre-metamorphic sulfide occurrences in the Spruce Creek Sequence, the Keevy Peak Formation and Totatlanika Schist, some of which were regarded as vein-fault deposits by previous workers. Brief geologic descriptions of these occurrences along with assay results have been provided in tables 9 and 10.

Spruce Creek Sequence deposits

Notable stratiform sulfide deposits in the Spruce Creek Sequence include the Lloyd and Saddle prospects (loc. 56, 47; pl. 1), and two unnamed occurrences near Spruce Peak and on Kankone Peak respectively (pros. 66c, 68). The Lloyd prospect is hosted in actinolite bearing chloritic-epidote semischist of the Psf unit, about 300 m east of the junction of the North and West forks of Glenn Creek. A 10 m long adit explores the deposit, which consists of thin laminations up to 2 cm thick of chalcopyrite, sphalerite, and minor galena that appear to parallel compositional banding in the host lithlogy. The sulfide bands have apparently been folded during f_2 deformation along with the host semischist. Additionally, polished sections show incipient micro-displacements of sulfide bands on the order of a few mm along S_2 slip surfaces. The deposit reaches a maximum thickness of 1 m and can only be traced a few tens of meters along strike. Assays as high as 2.16% copper and 3.98% zinc have been obtained from grab samples near the portal, but this is probably not an accurate analysis of the zone.

A similar sulfide occurrence is situated on the north shoulder of Kankone Peak at the 4200 foot elevation (loc. 68) where disseminated chalcopyrite, pyrite, and minor sphalerite are concentrated in 3 cm thick epidote-chlorite laminations in actinolitic greenschist of the Psf unit. At least four thin horizons less than 1/2 m thick have been traced eastward across the slopes for about 100 m where they are buried in talus. These sulfides may have replaced favorable zones in the greenschist during regional metamorphism or hydrothermal activity, but metallic content, geometry, and mode of occurrence suggest a stratiform accumulation of sulfides.

Trenching and pit development at the Saddle Prospect (pros. 47) east of the Chlorine Lode have disclosed several discontinuous pods of massive pyrite up to 1/3 m thick in metafelsite of the Psf unit. These lenticular zones of sulfide gossan parallel compositional banding in their host lithology, but appear to be largely devoid of base or precious metal values (tab. 10). Several unnamed occurrences 1 km east of Spruce Peak along a ridgeline overlooking Caribou Creek Valley consist of pyritiferous zones several meters thick within both graphitic schist of the Psg unit and metafelsite of the Psf unit. The mineralization has produced a strong limonitic gossan along the ridge and scree slopes that can be traced for over 1 km along strike. As at the Saddle prospect, the pyritiferous zones appear to be largely devoid of base or previous metal values (tab. 10).

Hawley (1977) reports that bulk samples of unmineralized graphitic schist interlayered with limy units on Eldorado Creek (Psg unit, this study) contain up to 160 ppm copper, 255 ppm lead, 575 ppm zinc, 12 ppm silver, and 20 ppm molybdenum. He also reports disseminated chalcopyrite and strong copper soil anomalies in metafelsite exposed on Alpha Ridge and north of Friday Creek airstrip (tentatively Psf unit) neither of which are believed to be associated with the nearby Alpha, Whistler, and Bright Light vein-fault deposits (pros. 9, 11, 12; pl. 1).

The origin of the stratiform mineralization in the Spruce Creek Sequence is poorly understood. Exposures are generally poor and only cursory examinations have been made by the author. No wall rock alteration or mineral paragenesis studies were attempted. Most occurrences described here are hosted in Spruce Creek Sequence lithologies of dominantly volcanic or volcanoclastic(?) parentage. Gilbert and Bundtzen (1979) report twenty sulfur isotopic analyses from stratiform occurrences from metamorphic rocks of the north-central Alaska Range. They report S^{34}o/oo values of +11.7 and +9.0 for chalcopyrite and sphalerite respectively from the Lloyd Prospect. The small sample size of their study limits geological interpretation, but sulfides from the Lloyd and other prospects in the Spruce Creek Sequence and Totatlanika Schist appear to be enriched by the heavier sulfur isotope during the metallic sulfide phase, typical of many volcanogenic massive sulfide settings (Stanton and Rafter, 1972). The average S^{34}o/oo value for all deposits in the Bonnifield and Kantishna Districts is +10.5; this contrasts with analyses from hydrothermal vein or porphyry stockwork deposits, which show fairly narrow isotopic ranges skewed toward the lighter (negative) isotopes (Jensen, 1959).

Known stratiform occurrences in the Spruce Creek Sequence are of subeconomic grade and tonnage. Never-the-less their presence supports the author's contention that base and precious metals in vein-faults in the Kantishna District may have been remobilized from metalliferous Spruce Creek Sequence lithologies during hydraulic fracturing and dewatering of volatiles by Cretaceous-to-Paloecene Dike swarm intrusion.

Metz (1977) has proposed that Kantishna and other districts of Interior Alaska be examined for stratiform antimony-mercury-tungsten deposits as have been successfully developed and mined in Europe and the Mediterranean region. He based this conclusion on (1) the presence of favorable host lithologies (basic metavolcanic rocks), (2) Early Paleozoic greenschist facies metamorphic rocks, (3) subduction or rift related volcanism and (4) presence of either mercury, antimony, or tungsten. The numerous massive stibnite-quartz lodes (type 1) and scheelite in both type 2 and type 3 vein-fault deposits described here, their preferential emplacement into lithologies of the Spruce Creek Sequence and the calc-alkaline chemistry of Spruce Creek Sequences metavolcanic rocks support Metz's (1977) contention that the southern Kantishna District is a good place to look for stratabound scheelite-stibnite ± mercury lodes.

Totatlanika Schist and Keevy Peak Formation deposits

Massive and disseminated sulfides and sulfates are hosted in lithologies of the Totatlanika Schist and Keevy Peak in the study area. The two major areas of sulfide concentrations are associated with metafelsite centers in the Totatlanika Schist. The most extensive mineralization examined is a well developed gossan zone in the Mtr unit west of Chitsia Creek that varies from 50 to 300 m wide and can be traced along strike for almost 8 km (pros. 80, 80a, 81; fig. 63). This mineralized zone, found wholly within felsic metavolcanic rocks, locally contains up to 30% visible sulfide (mainly pyrite) when fresh; but usually, the sulfides have been leached out by weathering. No base metal sulfides were recognized in the field, but polished sections from two localities show exsolved blebs of sphalerite in the euhedral pyrite grains. Geochemical analyses of 14 chip samples collected by the author and T. E. Smith and 12 collected by Hawley (1977) range from 0.05 to 0.52% zinc, and several hundred ppm lead and copper (tab. 10) throughout the 8 km long zone. Stream sediment samples collected in streams draining the zone by Bundtzen and others (1976) contain strong lead, zinc, and silver anomalies. Hawley (1977) suggests that the entire zone, although probably of subeconomic grade, constitutes a several billion ton low grade zinc resource.

A massive barite-galena-pyrite lens up to 3 m thick and traceable for 200 m along strike forms a prominent leached gossan zone on the southwest ridge of Chitsia Mountain (pros. 84; pl. 1). This occurrence is poorly exposed and the author's mineral investigation consisted of examining and tracking rubble along a steep scree slope below the ridge line. The mineralization is apparently hosted in greenish gray tuffaceous phyllite and interbedded carbonaceous phyllite of the Mts unit immediately adjacent to a thick domical accumulation of metarhyolite porphyry (Mtr unit). Sulfide and barite bands appear to be parallel to compositional banding in the phyllite. The mineralization overlies basic metavolcanic rocks of the Totatlanika Schist and appears to be midway through the

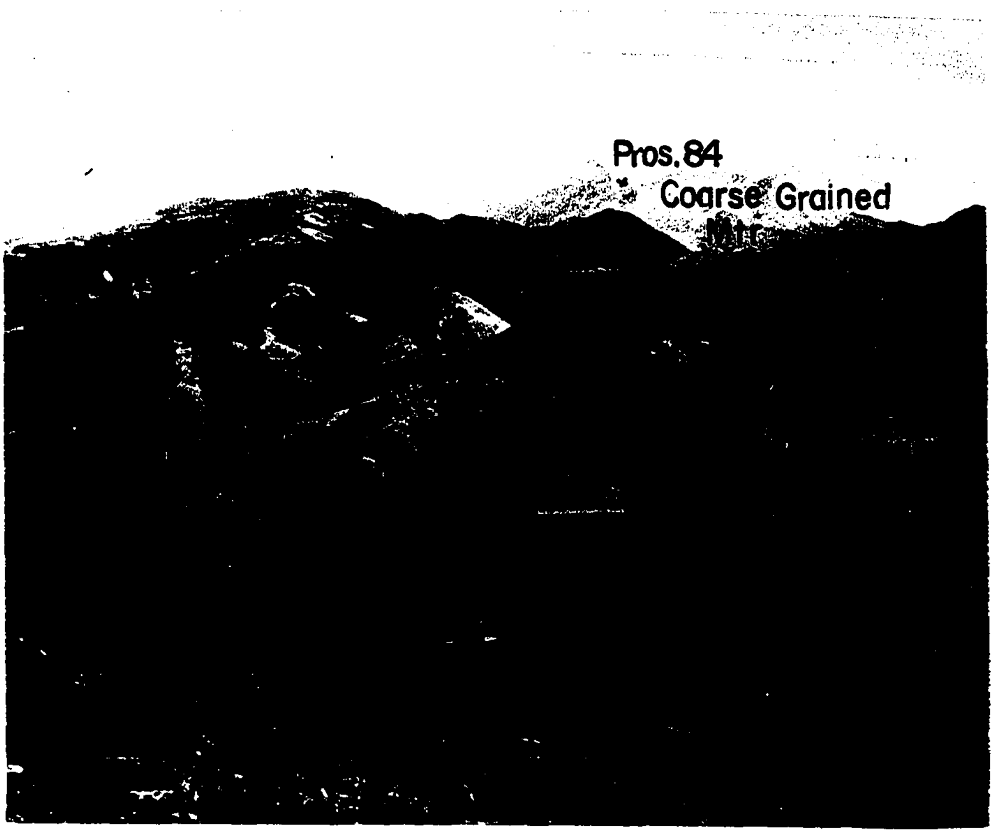


Figure 63. Prominent gossans and base metal occurrences in Chitsia Mountain area, view northeast.

section composed of felsic metavolcanic and volcaniclastic rocks. A conspicuous zone of barite veins and layers 3-10 cm thick cut and overlie tuffaceous phyllite host above the ore horizon. Recorded assay values of up to 40% barite, 10% lead, and 3 oz/ton silver from these deposits (tab. 10; Hawley, 1977) are probably not accurate analyses of the zone. A cerrusite-limonite gossan several meters thick and of undetermined length occurs at approximately the same stratigraphic position 2 km west of the Chitsia Mountain occurrences. Relict cores of galena can be found in feather light, dark reddish brown, boxwork gossan. Likewise, limonitic phyllite collected in rubble 3 km east of Chitsia Mountain at approximately the same stratigraphic horizon contains several thousand ppm combined lead, and zinc. All three zones appear to collectively define a several km long mineralized horizon midway through the Totatlanika Schist metavolcanic section.

Poorly understood disseminated and massive pyrite occurrences are present in dark gray slates of the Keevy Peak Formation on Moonlight and Marten Creeks. The fine grained sulfides are confined to thin laminations less than 1 cm thick in graphitic rich units in the slate. Although no base metal sulfides are recognized, stream sediment samples collected by Bundtzen and others (1976) and Hawley (1977) from streams draining these pyritiferous areas contain up to 1000 ppm combined lead and zinc.

The origins of stratiform mineralization in the Totatlanika Schist and Keevy Peak Formation are not well understood by the author. No wall rock alteration, mineral zoning, or paragenetic studies have been completed. Only a crude mineral zoning of barite overlying base metal sulfides was recognized at the Chitsia Mountain occurrence. Regional work by Hawley (1977), Gilbert and Bundtzen (1979), and Freeman (1980) suggest that stratiform mineralization in the Totatlanika Schist can best be classified as volcanogenic massive sulfide deposits hosted in calc-alkaline volcanic rocks of mid-Paleozoic age during early stages of subduction. The exhalitive barite zones that appear to overlie sulfide zones at the Chitsia Mountain occurrences are comparable to those described by Lambert and Sato (1974) for the barite (type b) and black ore (type 4) of the Kuroko District in Japan, which are associated with the late stage development of a Miocene volcanic arc. It is not clear whether the Totatlanika Schist stratiform occurrences represent proximal, offsite, or distal accumulations of sulfides from a volcanic vent system. The massive and disseminated sulfides hosted in metarhyolite flow sequences west of Chitsia Creek may represent successive outgassing of metalliferous brines through volcanic flows during mid-to-late stage rhyolitic eruptive sequences as suggested by Hutchinson (1973). Barite rich volcanogenic sulfide deposits adjacent to felsic volcanic rocks such as the Chitsia Mountain occurrences are generally considered proximal or offsite, rather than distal deposits (Plimer, 1978). The origin of sulfide laminations in slates and phyllites of the Keevy Peak Formation are unknown.

Metalliferous skarns

Three of the previously described hornfels and skarn zones (Th unit) contain trace to minor amounts of base metal sulfides. The Iron Dome occurrence on Eldorado Creek (pros. 8) consists of pyrite, minor sphalerite, and chalcopyrite, as disseminated zones and discontinuous pods less than 5 m across in a vesuvianite-zoisite bearing tactite. A shear zone occurs near the base of the dome at the 2400 foot elevation and much of the exposed outcrop area is brecciated. Morrison (1964, p. 42-

43) collected a sulfide bearing sample on the east side of the Dome which contained 1 oz/ton silver.

The Little Caribou skarn (loc. 77a,b) consists of massive and disseminated magnetite, hematite, sphalerite and chalcopyrite that have replaced a 1 m thick carbonate lense interbedded with pelitic schist. The banded metallic oxides and sulfides are interlayered with euhedral tremolite, epidote, and garnet porphyroblasts, which collectively constitute 50-75% of the rock zone. Strike length of the mineralized pod is believed to be less than 25 m. Several grab samples collected by the author range from 0.05 to 0.37% zinc and traces of silver. Stream sediment samples collected in Little Caribou Creek are anomalous in zinc. Hawley (1977) reported the presence of low grade stibnite mineralization as rubble about 500 m north of the skarn zone.

An unnamed tactite zone in marble east of Little Caribou Creek (pros. 78) consists of irregular pods of disseminated chacopyrite, galena, sphalerite, and magnetite in a zoisite-tremolite-calcite skarn. The zone is exposed in a single resistant outcrop protruding through vegetation and contact relations with other lithologies and geometry of the deposits are not known. In the outcrop examined, the base metal sulfides never constituted more than 5% of a given area. Maximum assays of 0.18% zinc, 0.067% lead, and a trace of silver were obtained from chip samples (tab. 10).

The author examined all hand specimens of skarn collected in the field with a black light, but failed to detect the fluorescent minerals scheelite or fluorite. The mineralogy of the skarns suggest crystallization in the albite epidote-to-hornblende hornfels zones of static metamorphism. According to Kennedy (1953), this type of mineral assemblage probably formed at low CO_2 pressures under at most a few hundred kilobars of pressure. A depth of 1 km is equal to a goestatic pressure of 250 kilobars. Although all metalliferous skarns examined appear to be well below economic grades and tonnages, the author suggests that they represent a new type of mineral exploration target previously unrecognized in the district.

Placer Gold Deposits

Introduction

Placer gold found in streams originating in the Kantishna Hills was derived from previously described hardrock lodes that are hosted in or intrude the polymetamorphic bedrock terrane. Its economic extraction from Eureka, Friday, Caribou, Glacier, Glenn, Spruce, Yellow, Rainy, Moose, Little Moose, Crooked, and Stampede Creeks has constituted a large portion of past and present mining activity in the study area. Descriptions by Brooks (1911), Capps (1918), and Davis (1922) still remain the best detailed sources for heavy mineral placer deposits in the Kantishna Mining District. The author relies heavily on their work during the following discussions, augmented by his own field observations and data collected during 1975 and 1976.

Geomorphology

Most of the streams carrying economic concentrations of placer gold head in open 'V' shaped valleys formed by the convergence of two or more tributaries. The lower portions of the valleys are narrow and steep walled canyons until they break out onto broad terraced, gravel covered lowlands. The lower broad terraced valleys contain rounded gravels derived from distal provenance in the core of the Alaska Range, which are easily distinguished from locally derived polymetamorphic cobbles in smaller V-shaped creeks. Examples in the study area of the former and later drainages are Moose and Eureka Creeks, respectively.

Youthful gold bearing gravels in the principal producing creeks consist of thin, poorly stratified deposits rarely more than 3 m thick and composed of subangular to subrounded clasts of polymetamorphic schist and quartz almost entirely of local derivation. The gravel deposits markedly thicken as they converge on the larger drainages such as Moose, Glacier and Caribou Creeks beyond the confines of narrow canyons. Gold concentrations in the tributaries are usually confined to the last 10-20 cm of gravel overlying bedrock, the bedrock surface itself, and within cracks and weathered zones in the bedrock that locally approach 1 m in depth.

Brooks (1911, p. 177-178) noted that exceptionally rich concentrations of gold, probably the richest mined in the Kantishna District, occurred near the mouth of Eureka Creek, where hydraulic stream gradient changes from 70 m/km to 50 m/km. He similarly noted a concentration of gold placers on lower Glacier Creek at a point where it breaks out of the rugged bedrock hills; here the stream gradient changes from 55-60 m/km to about 40 m/km. Brooks (1911) concludes that the heavy mineral concentrations in these zones are either (1) the result of concentration of materials at a hydraulic flexure point (high → low gradient) or (2) the result of enrichment from auriferous terrace alluvium that occurs in both areas. The former hypothesis is consistent with ideas expressed by Mosley and Schumm (1977) who suggest that heavy mineral placers achieve maximum concentrations at the intersections of stream drainages or points of differing hydraulic gradients and changes in stream kenetics in the same drainage.

A popular model for development of mature heavy mineral placers has been summarized by Adams and others (1978) and Boyle (1979) who suggest that maximum heavy mineral placer concentration occurs at a time when degradation and downcutting of a stream ceases and aggradation begins. In an especially mature placer district, the Fairbanks District, Péwé (1975) has recognized at least three such cycles in which mild uplift results in downcutting, movement of heavy mineral placers into channels, transport downstream and followed by aggradation, burial, and preservation of placers. Kantishna District placers are examples of exceptionally immature heavy mineral concentrations due to steep stream gradients in youthful 'V' shaped streams caused by rapid regional uplift during late Quaternary. A reconnaissance study by the author on stream gradients of streams draining the mineralized zones in the southern Kantishna district is summarized in table 17. The results show that the principal producing creeks have stream gradients averaging 50 m/km, while minor producers average 75-125 m/km. Those streams with gradients exceeding 150 m/km such as Rainy, Canyon, Flat and Snoeshoe do not have a recorded production of gold even though they drain the same mineralized zones as the major producing creeks. This probably reflects the relative immaturity of the heavy mineral placers in the Kantishna District which are in a continual state of migration downstream to more stable base levels. Jim Fuksa (oral comm., 1977) believes that paystreaks in Friday Creek are found immediately below their hardrock sources. He has mined several distinctive pay zones on his claims which are proximal to rubble-trains of type 2 vein-faults on the adjacent hillside. He doubts that placer gold, which consists of coarse angular, quartz bearing nuggets exceeding 1 ounce in size, has moved far by the action of water (fig. 64).

Both Brooks (1911) and Capps (1918) have drawn attention to the abundance of ancient-to-recent debris slides on Eureka, Little Moose, Friday, and Glacier Creeks (Qsl, pl. 1). According to Capps (1918, p. 300), "mining companies have disclosed the fact that many paystreaks are buried in mud and debris many feet deep...A slide on Little Moose Creek flowed suddenly down on a placer operation burying the sluice, mining equipment, and pay cut with mud and debris 10 feet deep." Brooks (1911) suggests that these slides may be important mechanisms that transport auiferous rubble into stream drainages where the action of water washes and concentrates the liberated gold into paystreaks. Cheney and Patton (1967) hypothesize that many placer deposits, particularly those in rugged mountainous terrane, result from the concentrating force of infrequent and catastrophic floods, that rapidly scour channels and move heavy minerals to sights of concentration. This mechanism explains the relative absence of bedrock values above the bedrock pay zone in many mining districts, which has puzzled placer geologists over the years. The mass movement of auriferous debris flows (fig. 65) during torrential flooding, coupled with bedrock scouring of stream channels seems like a plausible mechanism for concentration of gold and heavy minerals in paystreaks of the Kantishna District.

Figure 64. Coarse gold from Friday Creek, Kantishna District.

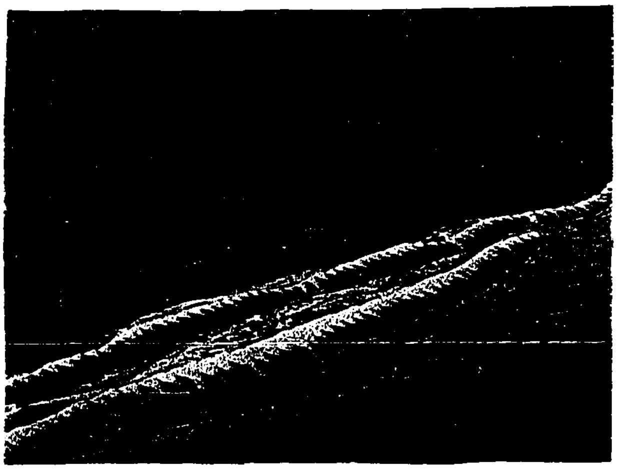


Figure 65. Inactive debris flows (d) and solifluction lobes of upper Caribou Creek. Note dragline tailing piles in stream floodplain.

Early and Late Wisconsinan Glaciation has affected distribution of gold placers in the Kantishna District. Early Wisconsinan ice advances of the Muldrow Glacier System overrode low hills below 3220 feet and traveled down Moose and Eldorado Creeks at least to the junction of Friday Creek depositing till along the southern margin of the Kantishna upland from Camp Denali eastward to Spruce Creek. Difluent ice streams eventually topped the divide between Myrtle Creek and Clearwater Fork terminating at the confluence of Gorge Creek. Late Wisconsinan ice advances did not reach the Kantishna upland, but cirque and restricted valley glaciers were active in the gold-bearing headwaters of Caribou, Spruce(?), Little Caribou, and Canyon Creeks.

The ice advances of both of these glaciations scoured and diluted pre-existing placer gold deposits, but more importantly, associated outwash deposits (Tb, pl. 1) reconcentrated gold derived from smaller tributary streams (fig. 66). A large percentage of the recorded gold production from the district has come from the latter tributary streams, but it has long been recognized that the terrace alluvium (Tb, pl. 1) on Moose and Lower Caribou Creeks contain large low grade reserves of auriferous gravels. During the last three years mining companies have operated large capacity dry-land dredges on Moose Creek between the confluence of Eureka and Friday Creeks. The pay zones in the terrace alluvium consists of fine gold on false bedrock clay horizons in 1-3 meter thick gravel rich channels. Although gold economic grade of these deposits is significantly less than those on more rugged tributary streams, the ease of processing the well sorted, boulder free gravels as well as

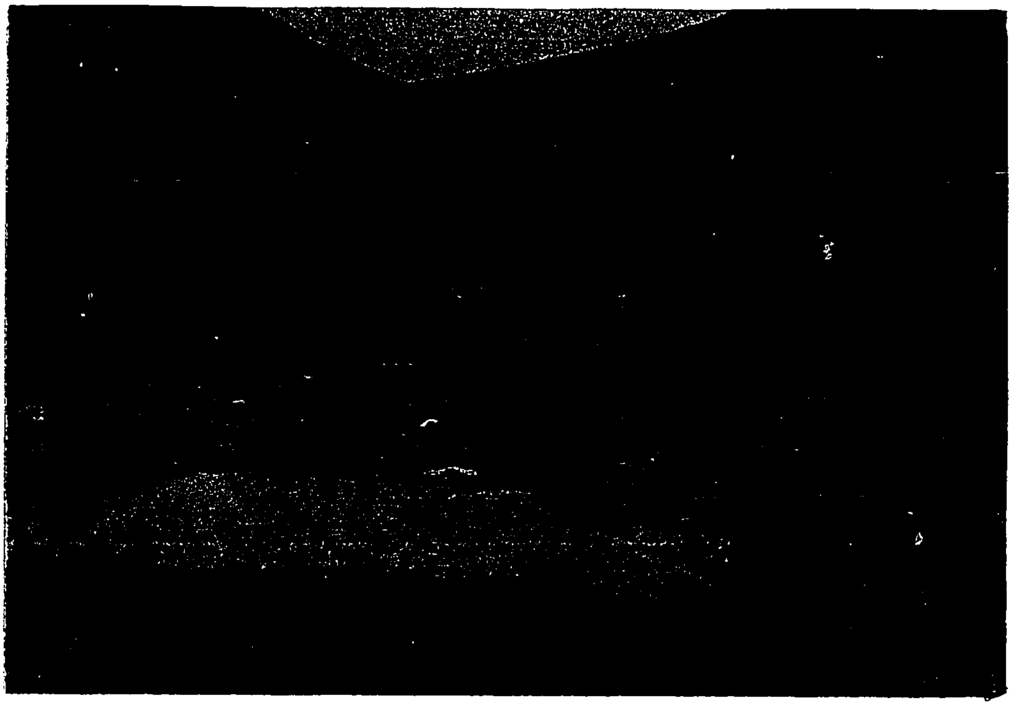


Figure 66. Placer operation at junction of Eldorado and Moose Creeks, circa. 1975; both streams have been invaded by Wisconsinan ice. Glaciofluvial gravels are processed in the washing plant; pay is confined to two distinctive false bedrock clay horizons.

the improved manuverability of equipment in the broad-terraced valleys has resulted in successful mining ventures.

Heavy mineral characteristics

Two types of placer gold are found in the district: (1) coarse angular, low fineness nuggets localized in steep tributary streams adjacent to known hardrock sources, and (2) flat, rounded, fine grained flakes of gold that rarely exceeds 0.1 ounce in size found in the broad open valley floor deposits of Moose and Lower Caribou Creeks, typical of gold worked by glacio-fluvial processes. Nuggets in most of the tributary streams rarely exceed 5 ounces in size, but one nugget won from lower Eureka Creek during the 1905 discovery year weighed 32 ounces. Thirteen and twenty ounce nuggets have been recovered from deposits on Glacier and Glenn Creeks respectively (Brooks, 1911).

Gold fineness values compiled from several sources are presented in table 18. The two best sources, Glover (1948) and Metz and Hawkins (1981), show divergent values with the latter study consistently reporting higher values. The former source quotes gold fineness as a percentage of the total content of the sample while the latter source expresses fineness as a ratio of gold to silver; i.e., (Au/Au + Ag) x 1000. This latter value is most often used in gold fineness studies Koch and Link (1971). The discrepancy between the two sources suggests that there are significant amounts of impurities in the Kantishna District placer gold besides silver.

Metz and Hawkins (1981) summarize gold fineness values from 800 creeks in every placer camp in Alaska. Their results show that the Kantishna District placer gold has the lowest mean value of 789, the lowest individual value of 567 (on Little Moose Creek), and the largest coefficient of variation (16 versus a state average of 4.33); of any district in Alaska. They suggest that the polymodal distribution of gold fineness values in the Kantishna District indicates different lode sources of gold and different processes of deposition for the placer gold. The author agrees with these conclusions and believes that both factors are responsible for the polymodal distribution of gold fineness in the study area.

Lode sources of placer gold in the district include type 1, 2, and 3 vein-faults, stratiform sulfide deposits, and metalliferous skarns. Relatively low fineness values of gold from Eureka, Friday and Yellow Creeks have their source in the concentration of type 2 vein-faults that crop out on Quigley Ridge and Wickersham Dome. High fineness gold (850 average) from Crooked Creek may have its lode source in the Crooked Creek Fault Zone or alternatively, from garnet amphibolite at the headwaters of the drainage, which was found to contain free gold during mineralogical garnet separation studies. Placer gold in upper Caribou, Little Moose and Crevice Creeks lack known concentrations of mineral deposits as gold sources.

Quaternary history has affected gold fineness values in the district. Placer gold won from Eldorado and Moose Creeks have fineness values 50-80 parts per thousand higher than gold found in the smaller 'V' shaped tributary streams nearby. This can be attributed to the reworking and milling effect of the glacio-fluvial gravels in the former streams that has resulted in larger surface areas on gold particles. According to

Forbes (1980), progressively larger surface areas on placer gold nuggets results in preferential leaching out of impurities and higher fineness values.

Mineralogical identifications of heavy minerals from the author's panned samples and mining company concentrates are presented in table 19. These results and those reported by previous workers demonstrate the wide variety of minerals that are derived from polymetallic vein-faults, skarns and stratiform sulfide occurrences in the study area. The abundance of cassiterite and scheelite in Caribou and Glenn Creeks has puzzled previous workers such as Capps (1918) and Davis (1922). According to E. Mauer (pers. comm., 1977), scheelite boulders as large as 12 inches in diameter were encountered by the Carrington Company dry-land dredge on upper Caribou Creek. Known lode sources for these minerals have not been found suggesting that the Glenn and Caribou Creek drainages deserve more detailed examination.

Economic potential

The author agrees with conclusions of Chadwick (1976) and Hawley (1977) who classify future placer potential of the area into two categories: (1) limited auriferous gravel deposits in the steep tributary streams which account for most of the gold production to date, and (2) large volume auriferous terrace alluvium on Moose, Caribou and Glacier Creeks beyond the limits of the Kantishna upland. Most of the former deposits have been worked at least twice and future mine operators must employ enhanced recovery systems for recovery of fine gold (here-to-fore largely lost), mine side pay left by previous operations, and remove debris slides that overlie paystreaks where economically justified. The latter terrace deposits contain the largest reserves left in the district. A feasibility study conducted by the Carrington Company (unauthored, 1925) on the Lea of lower Caribou Creek (pl. 1) demonstrated an estimated resource of 44 million cubic yards of auriferous gravels--thought at the time to be economically viable (the author has not seen specific grade estimates from the deposit). The results of mining company operations on Moose Creek during the last several years suggests that the large low grade reserves in terrace alluvium can be economically viable; however, large scale hydraulic mining ventures exploiting similar deposits on Moose and Caribou Creeks during the 1920's proved to be unsuccessful (Bundtzen, 1978).

GEOLOGIC HISTORY

The following summary, keyed to plate 4, attempts to integrate sequential deposition of rock units, metamorphism, structural deformation, mineralization, plutonic activity, glaciation and Quaternary to recent history of the Kantishna Hills. During Late Precambrian to Early(?) Paleozoic time, protoliths of the Birch Creek Schist were deposited as a sequence of medium-to-coarse grained, clastic rocks with minor pelitic and calcareous horizons. Tholeiitic mafic sills or flows are intercalated with sedimentary protoliths. The coarse grained quartz and feldspar rich protoliths that typify the Birch Creek Schist were probably deposited in relatively shallow water on a continental shelf adjacent to a cratonic land mass. Granitic plutonism and volcanism in the northern Birch Creek Schist terrane intruded and extruded over sedimentary facies of the Birch Creek Schist prior to the first regional dynamo-thermal metamorphic event.

Calc-alkaline volcanic and volcaniclastic rocks of the Spruce Creek Sequence are believed to represent an Early Paleozoic orogenic belt. Thoeiitic and calc-alkaline trends in mafic and felsic volcanic rocks respectively suggest that the Spruce Creek Sequence may represent initial arc deposits formed off the shelf deposits of the Birch Creek Schist. Metalliferous exhalitive(?) deposits were formed from volcanic vent systems.

Sometime prior to the Jurassic, or as Sherwood (1979) suggests, the pre-Devonian, the Birch Creek Schist was strongly deformed and progressively regionally metamorphosed from southeast to northwest. During this time the Spruce Creek Sequence experienced regional metamorphism in the greenschist facies prior to its present juxtapositioning against the Birch Creek Schist.

Afterwards, the Spruce Creek Sequence and Birch Creek Schist underwent compression from the southeast and northwest resulting in the formation of northwest plunging upright to isoclinal folds. An erosional surface develped on the folded, metamorphic terrane. During Middle-to-Late Devonian time a prograding coarsening upward sequence of calcareous muds, chert, pelitic shale, metasandstone and metaconglomerate was deposited on this unconformity. These Keevy Peak Formation lithologies represent a transition from basinal fine grained sediments at the base of the section to high energy submarine fan and turbidite deposits on a submarine slope at the top of the section.

During Late Devonian-to-Mississippian time, dikes and plugs rose through the slope deposits of the Keevy Peak Formation providing a magma source for calc-alkaline mafic-to-felsic volcanism of the Totatlanika Schist. These overlying volcanics with complexly interfingering tuffs and volcaniclastic sediments probably repesent the initial stages of an island arc along a subduction zone. Gilbert and Bundtzen (1979) have suggested that the Totatlanika Schist is only a small part of an extensive orogenic belt which formed on the margin of the North American continent in response to the Antler and related orogenies during Devonian-Mississippian time. It is possible that the organic rich fine-to-coarse clastic deposits of the Keevy Peak Formation partly reflect the eustatic rise in sea level that accompanies orogeny (Johnson, 1971). During late stages of volcanism, and subplutonic activity, metalliferous exhalitive deposits containing barite, lead and zinc formed at proximal or offsite locations from volcanic vent systems.

Regional dynamo-thermal metamorphism in Cretaceous time resulted in the development of greenschist facies mineral assemblages in protoliths of the Totatlanika Schist and Keevy Peak Formation and a cycle of retrogressive metamorphism in the Birch Creek Schist and Spruce Creek Sequence(?). The resultant prograde and retrograde events are easily recognized in the Birch Creek Schist because of mineral assemblages in disequilibrium, but masked in the Spruce Creek Sequence due to the same grade of regional metamorphism in the two metamorphic cycles.

After micas crystallized in mid-Cretaceous time, regional penetrative deformation in the form of upright to isoclinal f_2 folds, crenulations and kink bands, thrust faults and ductile high angle longitudinal faults deformed the terrane. The northeast trending folds intersected the previous fold style resulting in a classic 'egg-crate' structural configuration for the crystalline terrane. Fold deformation in the crystalline terrane culminated during Early(?) Tertiary in a parallel series of broad synclines and anticlines (f_3) which further warped the previous fold style and curved high angle fault traces. The deeper seated, more persistant ductile faulting style gradually changed to a more brittle fracture pattern probably in response to uplift in the crystalline complex. Tensional fractures opened up along the Kantishna Anticline allowing for hydraulic fracturing and leaching of metalliferous host lithologies in the Spruce Creek Sequence. Cretaceous-to-Paleocene dike swarm activity caused high temperature solutions containing arsenic, tungsten, iron and gold to deposit in fractures proximal to their source beds while somewhat lower temperature solutions composed of lead, zinc, copper, silver and gold migrated for some distance away from source beds and deposited in fractures in both the Birch Creek Schist and Spruce Creek Sequence. Mobile, low temperature epithermal antimony-silica solutions migrated farthest from older lode sources in the Spruce Creek Sequence and deposited massive sulfides in brittle competant hosts such as quartzite or garnet amphibolite. The dike swarm persisted through the end of the Paleocene and probably reflects sub-volcanic activity of the Teklanika Formation volcanic pile near Polychrome Mountain in Denali National Park. Where these small intrusives cut calcareous horizons, some metalliferous skarns developed.

Recurrent movement along high angle faults persisted throughout the Tertiary. Horsts and grabens formed favorable sites of deposition for fluvial and lacustrine silt, sand and gravel with clasts derived largely from local crystalline sources. During cycles of uplift throughout the Tertiary, heavy mineral placers formed and migrated downslope and downstream from lode sources.

The Early Pleistocene to Illinoian history of the study area is poorly understood and workers such as Péwé (1975) and Coulter and others (1966) debate the extent of the Plio-Pleistocene Browne Glaciation in the central Alaska Range. Never-the-less ice advances of this extensive glaciation undoubtedly affected the study area. Péwé (1975) believes that glaciation during Illinoian time represents a time of maximum Pleistocene ice accumulation in Alaska. Tilted, high level terrace deposits near Stampede attest to the influence of pre-Wisconsinan, probably Illinoian glaciation in the Kantishna Hills.

In Early Wisconsinan time, diffluent ice streams invaded and overrode low level divides into Moose and Eldorado Creeks and the Clearwater Fork. Ice scoured, diluted and buried heavy mineral placers on the entire length of Eldorado Creek and in lower portions of Eureka, Glenn, Spruce, and Friday Creeks. Extensive outwash channels in front of glaciers reworked gold that previously concentrated in Moose Creek Drainage from auriferous sources. These reworked placers formed on false-bottom impermeable clay horizons in the outwash sequences.

Late Wisconsinan ice streams terminated in classic moraines near Wonder Lake before reaching the Kantishna Upland, but prograding outwash gravels again reworked gold derived from auriferous tributaries. Isolated cirque and valley glaciers were active at the heads of Caribou, Canyon and Little Caribou Creeks.

A continuum of uplift in the study area during, before, and after glaciofluvial cycles resulted in the striking terrace levels observed today on the major streams. Large alluvial fans began forming in Wisconsinan time, but most are inactive today.

Holocene tectonics continued to affect heavy mineral placer formation in the study area. Bedrock instability in steep 'V' shaped canyons coupled with torrential floods moved mineralized colluvium into streams where the action of water concentrated gold and heavy minerals at favorable bedrock sites. The immature placers migrated downstream and downslope preferentially concentrating at hydraulic flexure points in streams or in drainages with unusually low gradients.

Modern stream alluvium, gravel fans and loess are being deposited on the surface of the study area. The shallow stream gravels in most upland watersheds and steep bedrock canyons suggest the region is still undergoing uplift.

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Table 1. Major element analyses (wt %) of 42 metamorphic rocks and mineral separates from Kantishna Hills, Alaska[a]

	1 75Ast1585.2 Amphibolite, pCg unit	2 75Ast1993.1 Amphibolite, pCg unit	3 75Ast1504.2 Stampede quartzite, pCs unit	4a 75Ast1687 Amphibolite dike, pCg unit	4b 75Ast1687 Pelitic schist, pCs unit	5 75BT201 orthoschist, pCfs unit
SiO_2	50.00	48.10	92.60	50.20	75.53	73.80
TiO_2	1.70	3.60	0.17	1.50	0.12	0.21
Al_2O_3	14.50	14.50	3.80	15.30	13.04	14.40
Fe_2O_3	11.00	13.20	0.93	10.60	0.40	1.60
FeO	0.00	0.00	0.00	0.00	1.28	0.00
MnO	0.19	0.18	0.01	0.17	0.03	0.02
MgO	7.00	4.90	0.19	7.50	0.15	0.26
CaO	10.50	10.00	0.06	10.50	0.77	1.60
Na_2O	1.80	3.40	0.04	2.00	6.24	2.50
K_2O	0.49	0.67	0.94	0.34	1.32	4.50
P_2O_5	0.07	0.30	0.02	0.06	0.04	0.02
H_2O^+	2.50	1.00	1.20	1.00	0.50	1.10
H_2O^-	0.10	0.10	0.10	0.10	0.00	0.10
Totals	99.85	99.95	100.06	99.27	99.42	100.11

	6a 75Ast2000 pCs unit	6b 75Ast2000a Quartzite, pCs unit	7 75Ast2908c pCfs unit	8 75Ast2907c pCfs unit	9 75Ast2957b Pelitic schist, pCs unit	10 75Ast1796 Pelitic schist, pCs unit
SiO_2	67.60	86.61	76.27	72.70	47.74	59.50
TiO_2	0.44	0.56	0.31	0.27	1.10	0.89
Al_2O_3	14.30	4.58	12.12	12.80	27.37	14.77
Fe_2O_3	1.74	0.70	0.57	0.50	1.44	1.64
FeO	1.69	2.16	1.35	1.09	6.03	6.17
MnO	0.03	0.10	0.02	0.02	0.11	0.16
MgO	1.60	1.51	0.17	0.28	2.75	3.12
CaO	5.55	0.40	0.61	1.48	0.31	0.67
Na_2O	2.87	0.12	6.56	5.21	0.86	1.13
K_2O	2.16	1.30	0.41	1.93	7.51	4.23
P_2O_5	1.43	0.10	0.06	0.53	0.04	0.08
H_2O^-	0.09	0.56	0.51	0.08	4.29	3.14
H_2O^+	0.00	1.56	0.00	0.00	0.00	0.00
Totals	99.50	100.26	98.96	96.89	99.55	99.80

[a]Numbers keyed to locations on plate 1. Whole rock analyses (1-29) by X-ray fluorescence, DGGS Minerals Laboratory. Analyses of mineral separates (41-51) by X-ray fluorescence, Technical Laboratories, Mississauga, Ontario Canada.

TABLE 1 (Continued)

	11 76BT192 Pelitic schist, pCs unit	12 76BT92 Pelitic schist, pCs unit	13 75BT2027 Metafelsite, Psf unit	14 75Ast2969 Greenschist, Psf unit	15 75Ast1813 Greenschist, Psf unit	16 75Ast1972 Greenschist, Psf unit	17 75Ast1881a Greenschist, Psf unit
SiO_2	70.00	73.36	74.90	46.79	45.28	51.24	75.25
TiO_2	0.74	0.32	0.25	1.14	1.27	1.55	0.36
Al_2O_3	14.56	12.99	12.80	15.28	16.11	14.62	12.08
Fe_2O_3	1.18	0.72	1.00	3.23	2.23	2.07	0.84
FeO	4.19	2.21	0.00	6.39	7.34	7.59	1.08
MnO	0.10	0.04	0.01	0.21	0.16	0.16	0.03
MgO	1.94	1.09	0.18	10.04	9.45	6.85	0.26
CaO	0.96	0.50	0.13	7.26	8.31	8.41	1.63
Na_2O	1.54	4.16	3.90	2.14	0.21	4.61	1.55
K_2O	3.37	3.06	3.70	0.00	3.85	0.10	3.49
P_2O_5	0.09	0.06	0.02	0.12	0.14	0.19	0.09
H_2O^+	1.56	0.99	1.50	9.25	5.06	1.69	2.53
H_2O^-	0.00	0.00	0.10	0.00	0.00	0.00	0.00
Totals	100.23	99.50	98.49	101.85	99.41	99.08	99.19

	18 75Ast1973 Metafelsite, Psf unit	19 75Ast1959 Metafelsite, Psf unit	20 75Ast1884d Metafelsite, Psf unit	21 75Ast2021 Greenschist, Psf unit	22 75Ast1943 Amphibolite, pCg unit	23 75BT1622 Mtr unit	24 75BT1706 Pillow basalt, Mtb unit
SiO_2	78.12	79.84	74.50	42.32	45.65	73.90	46.10
TiO_2	0.26	0.30	0.22	1.20	1.20	0.27	1.80
Al_2O_3	10.96	10.98	12.30	14.15	14.15	13.20	17.00
Fe_2O_3	0.32	0.35	0.39	1.59	1.59	3.00	11.10
FeO	0.90	0.36	0.87	9.45	9.45	0.00	0.00
MnO	0.03	0.01	0.01	0.18	0.18	0.01	0.17
MgO	0.05	0.00	0.31	11.52	11.52	1.00	6.00
CaO	1.41	0.35	5.43	7.03	7.03	0.10	9.80
Na_2O	3.59	6.01	4.69	1.09	1.09	5.30	3.40
K_2O	1.99	0.62	2.99	0.20	0.20	0.53	0.65
P_2O_5	0.11	0.05	0.96	0.22	0.22	0.03	0.20
H_2O^-	1.73	0.72	0.08	10.66	10.66	2.00	3.70
H_2O^+	0.00	0.00	0.00	0.00	0.00	0.10	0.10
Totals	99.47	99.59	102.75	99.61	102.94	99.44	100.02

TABLE 1 (Continued)

	25 75BT1730 Metarhyolite tuff, Mtr unit	26 75BT1736 Metafelsite (Mtr), Chitsia Mtn	27 75BT1744 Quartz-sericite schist, Mtr unit	28 75BT1890 Metaandesite, Mtb unit	29 75BT1776 Metasandstone, Mts unit
SiO_2	76.40	72.50	77.10	63.60	64.40
TiO_2	0.44	0.34	0.17	0.50	0.40
Al_2O_3	10.40	14.00	11.90	17.90	10.20
Fe_2O_3	2.90	1.20	1.10	1.00	7.10
FeO	0.00	0.00	0.00	0.00	0.00
MnO	0.05	0.10	0.02	0.00	0.03
MgO	1.00	0.37	0.36	0.17	10.30
CaO	0.64	0.81	0.18	0.03	0.08
Na_2O	2.60	2.00	3.00	3.50	0.08
K_2O	1.70	6.00	4.20	9.80	0.02
P_2O_5	0.03	0.06	0.09	0.02	0.02
H_2O^+	1.70	1.20	1.50	1.80	5.20
H_2O^-	0.10	0.10	0.10	0.30	0.10
Totals	97.96	98.68	99.72	98.62	97.93

	41 5875-1 hornblende from amphibolite	42 DT75-30 hornblende from amphibolite	43 DT75-34 hornblende from amphibolite	44 75-29 hornblende from amphibolite	45 75Ast5 garnet from pelitic schist (map #[illegible], pl. 2)
SiO_2	45.22	45.51	43.01	43.57	38.48
TiO_2	0.73	1.17	0.90	0.93	1.29
Al_2O_3	12.82	13.64	13.57	14.23	18.46
Fe_2O_3	14.95	19.01	21.42	16.12	32.65
FeO	0.00	0.00	0.00	0.00	0.00
MnO	0.22	0.17	0.11	0.18	0.80
MgO	11.94	9.50	7.96	11.53	1.09
CaO	11.38	11.04	9.86	10.75	6.01
Na_2O	1.13	1.27	1.49	1.29	0.23
K_2O	0.43	0.41	0.57	0.45	0.39
P_2O_5	0.06	0.06	0.06	0.05	0.37
H_2O^-	0.35	0.61	0.63	0.37	0.00
H_2O^+	0.35	0.00	0.00	0.34	0.00
Totals	99.58	102.39	99.58	99.81	99.77

TABLE 1 (Continued)

	46 76BT273 Garnet from pelitic schist (map #5, pl. 2)	47 76BT171 Garnet from pelitic schist (map #3, pl. 2)	48 DT75-31 Biotite, pelitic schist	49 DT75-31 White mica, pelitic schist	50 DT75-28 Biotite from pelitic schist	51 DT75-28 White mica from pelitic schist
SiO_2	34.17	35.10	34.05	50.43	34.83	47.20
TiO_2	0.68	0.84	3.23	0.70	2.05	0.55
Al_2O_3	19.71	19.71	16.61	31.20	17.57	32.15
Fe_2O_3	34.80	37.34	28.33	3.87	27.45	4.35
FeO	0.00	0.00	0.00	0.00	0.00	0.00
MnO	1.91	0.48	0.18	0.03	0.14	0.01
MgO	0.89	1.16	6.07	1.59	9.35	1.09
CaO	6.83	5.12	0.11	0.00	0.17	0.07
Na_2O	0.06	0.09	0.15	0.27	0.16	1.02
K_2O	0.11	0.13	9.42	10.28	5.06	9.38
P_2O_5	0.18	0.14	0.08	0.07	0.07	0.09
H_2O^+	0.12	0.00	1.19	0.32	1.11	3.15
H_2O^-	0.00	0.00	0.11	0.45	0.22	0.51
Totals	99.46	100.11	99.53	99.21	98.18	99.57

TABLE 2

MINERAL ASSEMBLAGES FROM METAMORPHIC ROCK UNITS OF THE

BIRCH CREEK SCHIST, KANTISHNA HILLS, ALASKA

Pelitic and quartzo-feldspathic schist and impure quartzites (pCs unit)

1. Prograde - relict oligoclase + garnet + white mica ± hornblende + biotite
   Retrograde - albite + zoisite/clinozoisite + chlorite + phengitic white mica + biotite ± calcite (30 sections)

2. Prograde - oligoclase + white mica + garnet
   Retrograde - albite + microcline + chlorite + phengite (14 sections)

3. Prograde - biotite + white mica + albite to oligoclase(?)
   Retrograde - chlorite + zoisite + microcline (22 sections)

(Tourmaline + zircon + quartz present in all samples)

Amphibolites and greenschist (pCg unit)

1. Prograde - oligoclase + hornblende + garnet + biotite ± white mica + sphene
   Retrograde - albite + zoisite/clinozoisite + chlorite + biotite ± actinolite ± calcite (25 sections)

2. Prograde - albite + actinolite + garnet ± biotite + sphene
   Retrograde - albite + zoisite/clinozoisite + chlorite ± calcite (6 sections)

3. Prograde - albite + hornblende + white mica
   Retrograde - albite + zoisite/clinozoisite ± tremolite/actinolite + chlorite (5 sections)

(Sphene + quartz present in all samples)

Felsic schist and gneiss (pCfs unit)

1. Prograde - oligoclase + white mica + biotite ± tourmaline ± garnet ± hornblende + orthoclase(?)
   Retrograde - albite + chlorite + biotite + microcline + zoisite (8 sections)

Calcareous schist (pCcs unit) and marble (pCm unit)

1. white mica + quartz + calcite + albite (3 sections)

2. chlorite + white mica + calcite + albite + pertnite + zoisite + philogophite (2 sections)

3. tremolite + diopside + albite + epidote + tourmaline + calcite + quartz (2 sections)

(Prograde and retrograde assemblages not determined for calcareous rocks)

Table 3. Estimates of 10 garnet compositions from the Kantishna Hills, Alaska (analyses by N.C. Veach) after methods described by Deer, Howie, and Zussman (1966, p. 21-31).

Map No. (pl. 2)	Field no.	Bedrock type	Mole-percent end members of garnet					Unit-cell edge (Angstroms)	Specific gravity	Index of refraction	MnO (%)
1	75Ast2900	Biotite-muscovite schist (pCs) unit	Almandine 56.8	Andradite 20.5	Grossular 15.9	Spessartine 5.6	Pyrope 1.2	11.630	3.45	1.806	2.40
2	75Ast1857b	Garnet amphibolite (pCg unit)	Andradite 68.4	Grossular 15.5	Spessartine 10.3	Pyrope 3.9	Almandine 1.9	11.636	3.86	1.808	4.45
3	76BT171	Pelitic schist (pCs unit)	Almandine 71.9	Pyrope 11.0	Andradite 10.0	Grossular 6.9	Spessartine 0.2	11.591	4.14	1.817	0.43
4	75Ast64a	Pelitic schist (pCs unit)	Almandine 57.5	Grossular 27.7	Andradite 9.2	Pyrope 3.6	Spessartine 2.0	11.615	3.85	1.808	0.85
4	75Ast64b	Amphibolite (unmappable size)	Almandine 59.6	Grossular 27.9	Andradite 8.3	Spessartine 2.5	Pyrope 1.7	11.627	3.83	1.808	1.10
5	76BT273	Pelitic schist (pCs unit)	Almandine 71.5	Grossular 13.3	Andradite 7.2	Pyrope 6.3	Spessartine 1.7	11.609	4.13	1.813	1.74
6	75Ast1598b	Pelitic schist (pCs unit)	Almandine 64.6	Pyrope 15.1	Andradite 11.1	Grossular 8.7	Spessartine 0.5	11.598	4.09	1.810	0.96
7	75Ast5	Pelitic schist (pCs unit)	Almandine 66.6	Pyrope 14.1	Andradite 11.1	Grossular 7.7	Spessartine 0.5	11.599	4.10	1.813	1.23
8	76BT253	Pelitic schist (pCs unit)	Almandine 64.8	Andradite 24.1	Grossular 8.0	Spessartine 1.7	Pyrope 1.4	11.624	3.75	1.806	0.75
9	76BT258	Pelitic schist (pCs unit)	Almandine 62.7	Pyrope 17.1	Andradite 12.0	Grossular 7.8	Spessartine 0.4	11.603	4.07	1.810	0.78

TABLE 4

MINERAL ASSEMBLAGES OF SPRUCE CREEK SEQUENCE LITHOLOGIES,

KANTISHNA HILLS, ALASKA

Pelitic and quartzo-feldspathic rocks (includes meta-igneous felsites)

1. plagioclse (albite) + zoisite + chlorite + white mica + alkali feldspar + calcite + quartz + tourmaline (6 sections)

2. albite ± oligoclase + chlorite + white mica + quartz + sphene ± tourmaline (14 sections)

3. albite + zoisite + calcite + chlorite ± actinolite-tremolite + biotite + white mica + alkali feldspar + quartz + tourmaline (15 sections)

Basic rocks

1. albite + zoisite/clinozoisite + chlorite + calcite + actinolite-tremolite + biotite ± white mica (2 sections) + quartz + sphene ± tourmaline (8 sections)

2. chlorite + quartz + zoisite + albite (3 sections)

Calcareous rocks

1. calcite + quartz + graphite (5 sections)

2. calcite + white mica + chlorite + alkali feldspar + albite + quartz (4 sections)

3. calcite + actinolite + chlorite + quartz + albite + white mica (1 section)

TABLE 5

MINERAL ASSEMBLAGES, METAMORPHIC ROCK UNITS, OF THE KEEVY PEAK FORMATION, KANTISHNA HILLS, ALASKA

Graphitic, and quartz rich phyllite and slate

1. white mica + quartz + graphite (7 sections)

2. white mica + quartz + calcite + chlorite (1 section)

Green phyllite (basic rocks)

1. albite + zoisite + calcite + white mica + alkali feldspar + chlorite + tourmaline (1 section)

2. chlorite + quartz + calcite + alkali feldspar (3 sections)

Calcareous rocks

1. calcite + white mica + quartz (3 sections)

Intermediate rocks (metagraywacke?)

1. white mica + quartz + alkali feldspar (2 sections)

TABLE 6

MINERAL ASSEMBLAGES, METAMORPHIC ROCK UNITS OF THE

TOTATLANIKA SCHIST, KANTISHNA HILLS, ALASKA

Quartzo-feldspathic phyllite and metafelsites, Mtr unit

1. white mica + alkali feldspar + quartz (11 thin sections)
2. white mica + albite + alkali feldspar + chlorite ± zoisite (7 thin sections)
3. white mica + albite + alkali feldspar ± chlorite + calcite (3 thin sections)

Greenschist and metabasalt (basic rocks), Mtb unit

1. epidote + calcite + chlorite + quartz + albite (5 thin sections)
2. actinolite + chlorite + epidote + albite + quartz + tourmaline (3 thin sections)
3. chlorite + albite + quartz + white mica + calcite (1 thin section)

Volcaniclastic metagraywacke and metatuff of intermediate composition, Mts and Mtms units

1. pennine + white mica + quartz + alkali feldspar + albite + calcite (8 thin sections)
2. epidote + chlorite + albite + quartz (1 thin section)
3. zeolite(?) + chlorite + alkali feldspar + quartz (1 thin section)
4. white mica + quartz + feldspar (3 thin sections)

Calcareous rocks in Mtm and Mtms units

1. epidote + white mica + chlorite + calcite + quartz (1 thin section)
2. white mica + calcite + quartz ± chlorite (5 thin sections)

TABLE 7

MODAL ANALYSES OF SELECTED MESOZOIC-CENOZOIC IGNEOUS ROCKS, KANTISHNA HILLS.
(based on 400 point count per thin section--in percent)[a]

Sample no.	Rock type unit	Location	Plg	Q	K-spar	Myr	Perth	Aug	Ol	Hrnb	B	Musc	Opaques
76BT Banjo M	Pyroxene, gabbro plug, Tb unit	Near Banjo Mine, (Pros. #35)	33.2	1.1	12.0	1.2	- -	12.9	2.9	- -	3.6	- -	5.5
76BT270	Olivine, gabbro dike, Tb unit	5 km northwest of Stampede mine	43.8	- -	3.6	- -	- -	3.9	4.9	- -	0.5	- -	11.6
DT75-32	Augite olivine gabbro plug, Tb unit	Near mouth of Clearwater Fork, Toklat River	35.2	6.6	4.9	- -	- -	6.6	6.9	- -	1.2	- -	27.1
75Ast3055a	Basalt dike, Tb unit	1-1/2 km east of headwaters, Rainy Creek	28.1	4.7	4.0	- -	- -	2.9	2.5	- -	6.1	- -	8.5
75Ast1958	Augite gabbro dike, Tb unit	3 km east of Banjo mine, Pros. #35	49.5	2.7	8.0	1.1	- -	13.8	0.9	- -	4.6	- -	3.3
75Ast1962a	K-spar-augite gabbro dike, Tb unit	1-1/2 km east of 75Ast1958	38.1	3.9	9.0	1.1	1.2	11.6	0.4	0.3	2.7	- -	2.9
75Ast1571.1	Augite basalt, Tb unit	4 km downstream from head of Crooked Creek	39.4	1.7	4.6	- -	- -	10.2	0.8	0.5	1.2	- -	5.1

Access	Ant-idd-lim	Chl-calc-clay alt	Remarks
1.4	13.2	12.7	Zoned plagioclase with An_{50} cores, An_{37} rims; small patches of myrmekite. Olive-green apatite and sphene contain sanadine; CI-15.
1.0	15.4	15.0	Fresh olivine phenocrysts; zoned plagioclase with An_{42} cores, undetermined rims. Augite altered to antigorite; calcite rims replace plagioclase.
3.7	5.6	2.0	Elliptical olivine grains altered to iddingsite and antigorite; plagioclase variable An_{42-65}; CI=40.
5.6	18.4	19.3	Antigorite-iddingsite rims around olivine and augite grains; CI=20; plagioclase zones with An_{53} cores, undetermined rims, abundant sphene and zircon accessories (geochemical analysis 39, table 8).
1.6	4.2	9.4	Medium-tan, fresh titano-augite altered plagioclase. An undetermined; tiny olivine grains; myrmekite intergrown with K-spar, dull green accessory mineral (geochemical analysis 33, table 8).
2.4	15.1	11.1	Extensive alteration of original olivine; augite veined with antigorite; sericite alteration of feldspar.
1.0	25.3	10.1	Pseudomorph of olivine is iddingsite; feldspars extensively sericitized (geochemical analysis 30, table 8).

Sample no.	Rock type unit	Location	Plg	Q	K-spar	Myr	Perth	Aug	Ol	Hrnb	B	Musc	Opaques
75Ast1859	Hornblende dacite, Thd unit	On ridge line east of Last Chance Creek	11.8	4.4	6.6	--	--	0.4	--	18.5	0.4	--	2.2
75Ast3055b	Quartz-K-spar porphyry, Tf unit	3 km east of Camp Denali	0.7	36.4	15.6	--	1.8	--	--	0.7	--	11.6	1.9
75Ast3046e	Felsite dike, Tf unit	Bunnell pros., #4 plug on Eldorado Creek	5.5	16.7	26.1	17.4	--	--	--	--	--	8.7	5.5
75Ast3055	Quartz-K-spar porphyry	Same site as 3055b	2.3	19.0	12.9	42.0	8.9	--	--	--	--	2.5	3.5
76BT162a	Porphyritic granodlorite(?), Tgd unit	4 km upstream from mouth of Gorge Creek	7.7	19.8	16.4	53.3	10.0	--	--	16.0	6.40	--	4.5
75Ast1684	Altered latite sill, Tqt unit	Headwaters, Chitsia Creek	5.4	29.9	39.9	--	--	--	--	--	--	7.3	3.4

[a]Modal analyses by T.K. Bundtzen.

Plg = plagioclase
Q = quartz
Myr = myrmekite
K-spar = alkali feldspar
Perth = perthite
Aug = augite
Ol = olivine
Hrnb = hornblende
B = biotite
Musc = muscovite
Access = accessory minerals
Ant-idd-lim = antigorite, iddingsite, or limonite
Chl = chlorite
Calc = calcite
CI = color index

TABLE 7 (Continued)

Access	Ant-idd-lim	Chl-calc-clay alt	Remarks
2.2	1.8	49.6	Pleocroic olivine, green-blue, euhedral hornblende; poikiblastic K-spar; extensive carbonate alteration of plagioclase and groundmass (geochemical analysis 32, table 8).
0.7	0.5	30.1	Altered feldspar and groundmass; former amphibole completely altered to opaques + chlorite; opaques are sulfides (geochemical analysis 38, table 8).
0.7	1.0	16.3	CI=5; opaques are entirely sulfides; inclusion-charged silicate minerals; sample largely altered.
1.1	1.8	4.9	Abundant myrmekite with 1.5:1 quartz-feldspar ratio; plagioclase An_{15-18}, inclusion-charged groundmass; perthite cores in myrmekite.
0.2	1.8	2.6	Myrmekite-rich; sericitized plagioclase An_{22-35}; honey-yellow apatite; blue-green amphibole; brown biotite; inclusion-charged silicates.
0.5	1.0	13.7	Altered feldspars; all silicates inclusion charged (geochemical analysis 31, table 8).

Table 8. Major element chemical analyses (wt %) of 11 igneous rocks from the Kantishna Hills, Alaska[a]

	30 75BT15712 Basalt dike, Tb unit	31 75BT1684 Quartz-rhyolite dike-sills; Tql unit	32 75BT1859 Hornblende dacite, Thd unit	33 75BT1958 Olivine gabbro sill, Tb unit	34 75Ast1987 Quartz K-spar porphyry unit	35 76BT162 Altered granodiorite sill, Tgd unit
SiO_2	46.60	76.00	64.00	51.10	73.00	66.20
TiO_2	1.90	0.04	0.59	1.80	0.14	0.69
Al_2O_3	16.20	13.60	14.70	15.50	14.70	13.10
Fe_2O_3	10.20	1.20	4.00	9.90	2.90	1.82
FeO	0.00	0.00	0.00	0.00	0.00	3.36
MnO	0.17	0.03	0.08	0.16	0.07	0.10
MgO	6.00	0.19	2.80	6.80	0.22	0.65
CaO	9.50	1.30	3.50	8.70	1.40	2.38
Na_2O	3.00	3.50	3.10	3.00	3.10	3.76
K_2O	0.99	1.90	4.80	1.40	3.40	5.16
P_2O_5	0.20	0.02	0.02	0.35	0.02	0.54
H_2O^+	4.70	2.40	1.70	1.40	2.00	0.20
H_2O^-	0.10	0.30	0.10	0.10	0.10	
	99.56	100.48	99.37	100.21	101.05	97.96
Norms						
QZ	0.51	43.66	16.52	3.78	36.89	17.20
OR	6.23	11.67	29.14	8.45	20.68	28.60
AB	28.71	32.66	28.60	27.52	28.66	29.20
AN	29.65	6.57	12.35	25.24	7.02	11.30
NE	0.00	0.00	0.00	0.00	0.00	0.00
LE	0.00	0.00	0.00	0.00	0.00	0.00
CO	0.00	3.94	0.00	0.00	3.85	0.00
KS	0.00	0.00	0.00	0.00	0.00	0.00
NS	0.00	0.00	0.00	0.00	0.00	0.00
CS	0.00	0.00	0.00	0.00	0.00	2.20
DI	10.28	0.00	1.89	8.62	0.00	7.30
HY	12.51	0.55	7.00	14.88	0.63	0.00
OL	0.00	0.00	0.00	0.00	0.00	0.00
MT	0.00	0.00	0.00	0.00	0.00	0.52
IL	0.28	0.05	0.13	0.26	0.11	0.47
AP	0.45	0.04	0.43	0.75	0.04	0.00
CC	0.00	0.00	0.00	0.00	0.00	2.50
HT	7.58	0.87	2.86	7.05	2.08	0.00
WO	0.00	0.00	0.00	0.00	0.00	0.51
TN	3.80	0.00	1.07	3.46	0.00	0.00
RU	0.00	0.00	0.00	0.00	0.04	0.00
AC	0.00	0.00	0.00	0.00	0.00	0.00
	100.00	100.01	99.99	100.01	100.00	99.80

[a]Numbers keyed to locations on plate 1; rapid-rock technique by Skyline Labs, Wheatridge, Colorado.

TABLE 8 (Continued)

36 76BT158 Dacite dike, Thd unit	37 75Ast2976a Ultramafic dike, Tu unit, serpentinized	38 75BT3055 Quartz-porphyry dike Tu unit	39 75BT3055a Olivine gabbro, Tb unit	40 75BT2825 Basalt dike, Tb unit
58.00	39.90	78.50	48.20	45.20
2.00	0.76	0.12	2.00	1.50
13.80	4.46	12.50	14.50	12.60
7.40	3.82	1.10	9.40	7.50
0.00	9.70	0.00	0.00	0.00
0.13	0.16	0.01	0.16	0.14
1.50	28.90	0.11	6.50	8.40
4.50	3.07	0.04	8.30	9.20
3.00	0.12	6.00	2.70	2.70
3.20	0.04	0.22	1.60	0.57
0.45	7.91	0.02	0.30	0.15
5.90	0.28	0.90	4.90	12.00
0.10		0.10	0.10	0.10
99.98	99.12	99.62	98.66	100.06
17.91		40.04	3.30	0.74
20.66		1.32	10.19	3.81
29.44		54.72	26.14	27.43
16.11		0.07	24.51	23.29
0.00	Not deter-	0.00	0.00	0.00
0.00	mined due to	0.00	0.00	0.00
0.00	high H_2O	2.62	0.00	0.00
0.00	content	0.00	0.00	0.00
0.00		0.00	0.00	0.00
0.00		0.00	0.00	0.00
4.06		0.00	8.77	17.57
2.50		0.31	14.97	17.46
0.00		0.00	0.00	0.00
0.00		0.00	0.00	0.00
0.22		0.02	0.27	0.25
1.03		0.04	0.68	0.35
0.00		0.00	0.00	0.00
5.64		0.78	7.07	5.92
0.00		0.00	0.00	0.00
3.05		0.00	4.10	3.17
0.40		0.08	0.00	0.00
0.00		0.00	0.00	0.00
101.02		100.00	100.00	99.99

Table 9. Geologic summary of lode mines and prospects in the Kantishna Hills, Alaska
(Numbers keyed to plate 1)

Prospect	Name(s)	Production	Structure, geologic description	Mineralogy	Remarks
1	"Antimony Mine" or Slate Creek deposit (Wells, 1933; Taylor Mine (Capps, 1916, p. 107).	At least 657 tons of ore with 45% Sb content.	Fissure vein trends N. 50° E., has 82° SE. dip, 0.5-6 m thick, at least 120 m of mineralized strike length; sericite schist country rock is also mineralized.	Massive stibnite-quartz vein, minor pyrite, boulangerite, cervantite, arsenopyrite.	Stibnite-boulangerite ores shipped intermittently 1942-79; large deposit with significant ore potential (pl. 3 and text).
2	Brooker Mountain prospect (this study).	None recorded	Fissure vein N. 75° E. vertical along fracture, 20 m of surface exposure chlorite-quartz-muscovite schist country rock (pCs).	Weathered stibnite-quartz vein, extensive limonitic stain.	Small 3- by 1-m pit exposes vein; no published information.
3	Upper Bunnell prospect (this study).	None recorded	N. 50°-55° E. steeply SE-dipping stringer vein in altered porphyry intrusive, individual veins 10-50 cm thick.	Stibnite, galena, pyrite, jamesonite(?), and boulangerite in quartz-calcite gangue; some anglesite oxidation.	Exposed in stream cut 100 m upstream from lower workings, Bunnell Prospect.
4	Bunnell prospect or Neversweat prospect (Wells, 1933).	1955 shipment of Kantishna lead-silver ore believed derived from this deposit.	Complexly faulted vein trending E-W to N. 70° E., dipping 50°-75° SE., system intruding quartz-porphyry body near its contact with country-rock quartz muscovite schist of pCs unit (pl. 1, pl. 3).	Quartz-carbonate-galena, tetrahedrite, stibnite, sphalerite, minor chalcopyrite, boulangerite, jamesonite, and scheelite in quartz-K-spar-carbonate veins.	Four adits driven into 60 m of vertical vein exposure; up to 1.5-m-thick, massive sulfide vein.
5	Arizona claims	None recorded	Gossan zone in pCs unit with generalized N. 20°-50° E. trend.	Limonite quartz in muscovite-chlorite quartzose schist.	Poorly defined mineralization above Bunnell-prospect porphyry.
6	Eagles Den or "Don Antimony" (Hawley, 1977).	None recorded	N. 30° W.-trending vein with 35° NE. dip, 1-6 m thick, 25 m of strike length exposed at surface. Intrudes muscovite-quartzose schist (pl. 3).	Massive quartz-stibnite vein; up to 1 m of massive stibnite on hanging wall of vein.	Very promising antimony deposit; deserves exploration.

TABLE 9 (Continued)

Prospect	Name(s)	Production	Structure, geologic description	Mineralogy	Remarks
7	Buaia Mountain prospect (Lucky Tuesday)	None recorded	E-W to S. 30° W.-trending 1-m-thick zone intrudes quartz-rich pCs unit.	Stibnite-quartz.	1-3-m-wide, caved prospect pit.
8	________[a] (75Ast3040)	None recorded	N. 30° E., 20° NW. dip, possibly barren fissure-quartz vein; intrudes siliceous quartz muscovite schist.	Limonitic quartz + minor pyrite.	Poorly exposed pit.
9	Alpha mine (Virginia City claims)	25 tons high-grade silver ore	N. 70° E. trend of 3 veins 0.5-3 m thick; 100 m of exposed strike length intrudes tan-weathered mica-quartzose schist (pCs unit).	Galena, jamesonite, stibnite, sphalerite, siderite, pyrite, and arsenopyrite; minor tetrahedrite and boulangerite.	400-m-long gossan trends SE from Alpha; trenches and underground working are caved. High siderite content in massive sulfides (pl. 3).
10	Alpha Ridge claim	None recorded	N.-55°-E.-trending, 50°-SE.-dipping vein with erratic continuation.	Quartz, pyrite, and limonite (in pCs graphitic schist).	Small pit.
11	Whistler	None recorded	NE-trending massive sulfide-vein system trends along 150 m of strike length.	Galena, sphalerite, tetrahedrite, pyrite, boulangerite, quartz, siderite.	
12	Bright Light	None recorded	Vein trends more N-NE than Whistler.	Galena, limonite, sphalerite, quartz, siderite.	Probable continuation of Whistler vein-fault; poorly exposed.
13	Eldorado No. 3	None recorded	N. 75° E. vertical vein, 0.75 to 2 m thick intrudes pure muscovite marble; traceable for 45 m of strike length.	Stibnite, carbonate, and stibiconite, with euhedral quartz-crystal cavities.	Virtually unexplored vein.
14	________ (75Ast2003)	None recorded	N. 70° E.-trending, 10° SE.-dipping 'vein' of quartz sulfides parallel to carbonate bedrock (Pag unit).	Pyrite, sphalerite, and euhedral quartz cavities; minor marcasite; disseminated arsenopyrite in wall rock.	Occurrence of stratabound vein in carbonate rock. Completely unexplored. Very similar to Pros. 13.

[a]There are two 'Silver King' prospects in district; the other is a portion of the Red Top vein system (prospect 19).

Prospect	Name(s)	Production	Structure, geologic description	Mineralogy	Remarks
15	(75Ast2002)	None recorded	N. 35° E. vein with 80° SE. dip, 10-80 cm thick, intrudes gray quartzite (pCs unit) and siliceous phyllite (Psf).	Quartz, siderite, arsenopyrite, pyrite, and minor to trace galena.	Small, well exposed examples of Kantishna vein. Lithologies similar to metamorphic units at Stampede.
16	Iron Dome skarn	None recorded	Poorly defined sulfide-skarn mineralization in hornfels zone about 1/2 sq km in extent.	Tourmaline, garnet, magnetite, pyrite, clinozoisite, vesuvianite, wollastonite.	Appears low grade but is good example of skarn mineralization in Kantishna district.
17	Eureka-stibnite part of 'Pick' claim block.	50 tons in 1915	Caved quartz-sulfide vein up to 1 m thick.	Stibnite forms dentritic intergrowths into quartz gangue.	Caved adit and considerable dump of oxidized ore. Produced ore during the early days; unknown potential.
18	Friday Rim (75Ast1998)	None recorded	Intrudes pCs-unit quartzite.	Quartz, siderite, and minor pyrite.	1- by 1-m prospect pit, caved; appears low grade.
19	Red Top (includes Silver King extension)	182 tons high-grade Ag ore.	N. 70° E. vertical vein 1-3 m thick; crosscutting fracture system localizes high-grade shoots.	Galena, sphalerite, arsenopyrite, siderite, tetrahedrite, polybasite, pyrargyrite, pyrite.	Well known for very high grade ore, 182 tons averaged 237 oz silver/ton and 1.1 oz gold/ton; caved workings (pl. 3).
20	Galena	100 tons high-grade Ag ore.	N. 45° E.-trending, 65° SE.-dipping vein 2 m thick, intrudes Psg unit.	Galena, arsenopyrite, pyrite, sphalerite, tetrahedrite, siderite, quartz, minor chalcopyrite.	High-grade ore mined in past, good chance of finding additional tonnage underground. Lower grade ore left in dump. Caved underground workings; portal can be entered 3 m.
21	Lucky Strike	None recorded	N. 55° E.-trending vein with 84° SE. dip, about 2 m thick; about 65 m of strike length exposed on the surface; intrudes Psf unit.	Major quartz, galena, and sphalerite; minor siderite, tetrahedrite, free gold.	Open cuts and caved adit exposed 40 m of strike length of vein. Would be ideal location to explore.

Prospect	Name(s)	Production	Structure, geologic description	Mineralogy	Remarks
22	a) Star b) Friday c) Martha Q d) Polly Wonder (Dalton Group)	4-15 tons high grade silver ore.	a) 6-in. stringer of galena and sphalerite trending NW (Davis, 1922). b) NE extension of Red Top c) N. 15° W., 56° E.-dipping vein. d) EW, 65°-70° S.	Galena, tetrahedrite, pyrite, chalcopyrite in quartz-siderite gangue.	Part of Quigley-Ridge vein system total of 4 veins; about 200 m of strike length.
23	a) Francis b) Little Maud	"A few tons of ore" Davis (1922); Wells (1933)	a) N. 75° E. vertical vein fault. b) N. 55° E., 60°-70° SE.-dipping veins 0.5-3 thick.	Galena, sphalerite, pyrite, Siderite, quartz, minor tetrahedrite.	Part of Quigley-Ridge vein system.
24	Silver Pick (includes Darling Extension)	None known	Two veins, N. 88° E., 63° NW. and N. 65° SE., 67° SE., 400-500 m of traceable strike length.	Galena-sphalerite-arsenopyrite-tetrahedrite-siderite quartz pods, also scorodite-quartz vein material.	Seraphim (1961) completed extensive work on this vein and was impressed with potential tonnage but discouraged by general lack of high-grade ore pockets.
25	Gold Eagle	4 tons high-grade silver ore.	N. 65° E.-trending, 75° SE.-dipping vein, 0.5-3 m thick, 100 m of traceable strike length.	Same as Gold Dollar (26).	Probable extension of Gold Dollar claim; holds same potential.
26	Gold Dollar	638 tons high-grade silver ore.	N. 65° E.-trending, 75° SE.-dipping vein, 1-3 m thick, 125 m of traceable strike length.	Pyrite, arsenopyrite, galena, sphalerite, siderite, polybasite, tetrahedrite, and oxidized products.	Ore exposed in shaft. Was mined in 1973 (pl. 3).
27	Little Annie (includes Little Annie 2)	715 tons of high-grade silver ore.	N. 58° E.-trending vein, with steep SE dip, 200 m of traceable strike length, up to a few meters thick.	Galena, sphalerite, abundant siderite, tetrahedrite, polybasite, arsenopyrite, and pharmacosiderite, in quartz-azurite-malachite gangue.	Ore mined was a very thick lens of massive sulfides at intersection of NE fractures. Part of Gold Dollar-Gold Eagle vein system (pl. 3).
28	Gold King	None recorded	N. 80° E. vertical vein 2 m thick.	Disseminated arsenopyrite, galena, and sphalerite in quartz.	Poorly exposed.

TABLE 9 (Continued)

Prospect	Name(s)	Production	Structure, geologic description	Mineralogy	Remarks
29	East Gold King-Pittsburgh veins	None recorded	2-m-wide-quartz vein with sulfide and calcite (Davis, 1922).	- - -	- - -
30	Pennsylvania Keystone (includes William Julian Prospect and Perserverance Group)	None recorded	Two veins, N. 30° E., steeply dipping, and N. 65° E., 85° SE. over 450 m of mineralized strike length; variable 0.5-3 m thick. Large iron-stained vein at 2250-ft elevation.	Quartz, arsenopyrite, pyrite, galena, free gold, tetrahedrite, and scheelite.	Predominantly a gold-quartz deposit similar to Banjo or Jupitar-Mars veins (Pros. 35, 36).
31	White Hawk	None recorded	Several NE-trending veins 1 m thick, 150 m of traced strike length.	Quartz, siderite, tetrahedrite, boulangerite, sphalerite, pyrite; lead-antimony sulfosalts.	Poorly exposed in 1975. One of larger vein systems in lode line; caved workings.
32	Water Level claim	None recorded	N. 70° E.-trending, 65° NW.-dipping vein 1.2-2 m thick, much oxidation and shearing; 15 m of vein trenched.	Galena, tetrahedrite, siderite, minor quartz; extensive oxidation (cerussite + limonite).	High-grade silver prospect.
33	Sulphide claim	None recorded	50 m of strike length.	Quartz, pyrite, arsenopyrite, and scorodite, some boulangerite.	Unexplored, poorly exposed. Davis (1922) reports free gold on panning crushed ore.
34	Silver King[a] and Merry Widow	None recorded	N. 70° E.-trending, 65° NW.-dipping vein 1.2-2 m thick, much oxidation and shearing; 15 m of vein trenched.	Limonite, galena, pyrite, sphalerite, tetrahderite; minor chalcopyrite.	Extensive limonite gossan formed; some primary sulfides remain; high-grade silver prospect (pl. 3).
35	Banjo	6,260 oz gold, 7,113 oz silver, and about 20 tons of lead-zinc concentrates from 13,653 tons of ore.	NE-trending vein system 1-3 m wide cutting Psf unit.	Arsenopyrite, pyrite, scheelite, gold; minor galena-tetrahedrite, sphalerite, and scorodite.	Largest lode producer in the Kantishna; blocked ore left in workings at time of WW II closure. Underground workings are caved (pl. 3).

Prospect	Name(s)	Production	Structure, geologic description	Mineralogy	Remarks
36	Jupitar-Mars	Small tonnage added to Banjo production.	N. 65°-70° E. sulfide-quartz vein 2-3 m thick parallel to Banjo vein.	Arsenopyrite, pyrite, gold, scheelite, galena, sphalerite, quartz, minor calcite.	Gold-bearing vein is part of Banjo system (pl. 3).
37	Chlorine prospect	None recorded	Northeast vein probable extension of Jupitar-Mars.	Arsenopyrite, quartz, and pyrite with minor galena and sphalerite.	Caved pits.
38	75Ast1941, 1942 (near Blue-Bell prospect).	None recorded	N. 15° E.-trending vein; smaller veins shot through altered dike.	Pyritic and limonitic stain, minor siderite.	- - -
39	Flourence lode	None recorded	N. 10° E. vertical vein, 0.5-1 m thick, 10.5 m of strike length exposed.	Galena, tetrahedrite, siderite, minor sphalerite, polybasite, malachite, azurite, anglesite, goethite, cerussite.	High-grade ore shoot with visible polybasite. Caved shaft about 4 m deep.
40	(1949)	None recorded	N. 40° E.-trending (dip unknown) vein trenched for 25 m.	Major quartz and carbonate, minor fine-grained galena, arsenopyrite, pyrite.	Low-grade mineralized vein is poorly exposed.
41	Upper-Bosart vein	None recorded	N. 40°-60° E.-trending, steeply SE-dipping vein 0.3-1.5 m thick.	Quartz, carbonate, siderite, galena, tetrahedrite, sphalerite.	Probably upper extension of Bosart; largely unexplored; good mineral shows.
42	Bosart prospect	None recorded	N. 50° E. vertical vein intrudes unit pCs, 45 m of strike length exposed.	Quartz, siderite, galena, tetrahedrite, sphalerite, visible polybasite.	High-grade silver ore on dump; promising galena-silver prospect (pl. 3).
43a	Unnamed (75Ast2960)	None recorded	N. 30° W. vertical vein.	Arsenopyrite, pyrite, quartz.	Poorly known and poorly exposed.
43b	Unnamed (75Ast2964)	None recorded	NW-trending vein; intrudes chlorite schist of Psf unit.	Arsenopyrite, quartz, and boulangerite in quartz.	
44	Waterloo (75Ast1955)	None recorded	N. 10° W.-trending steeply dipping vein 0.6 m thick intrudes felsic phyllite of Psf unit.	Pyrite, galena, quartz, anglesite, carbonate; minor sphalerite and oxidized products.	High silver assay.

Prospect	Name(s)	Production	Structure, geologic description	Mineralogy	Remarks
45a	Weller or Parky prospect (Seraphim, 1961).	None recorded	N. 40° E., 60°-70° SW.-dipping vein 0.3-1.0 m thick, 15 m traceable strike intrudes Psg unit.	Galena, tetrahedrite, polybasite, quartz, minor sphalerite.	Very high grade ore shoot.
45b	Eureka or Griess prospect (Well, 1933; Capps, 1916)	None recorded	Quartz veinlets (N. 45° E., 60° NW.) lie parallel to black graphitic schists about 1.2 m thick (Capps, 1916).	Reported galena, chalcopyrite, tetrahedrite, malachite, azurite.	Did not visit this claim. Reported to have considerable copper; Hawley (1977) reports anomalous soil gossan.
46	(75Ast1959)	None recorded	N-S vertical zone 1-3 m thick in Psf unit.	Pyrite, quartz, arsenopyrite.	Silicified-pyritized zone parallel to foliation. Appears weakly mineralized.
47	Saddle prospect; 75Ast1960	None recorded	N. 10° E.-trending sulfide zone in schist, vein 1-3 m thick.	Pyrite-quartz, minor arsenopyrite.	Three trenches expose large siliceous-schist zone that appears pyritized; appears only weakly mineralized.
48	Unnamed (75Ast1964)	None recorded	N. 50° E.-trending, 30° NW.-dipping zone 0.3-1.2 m thick, intrudes Psg unit.	Pyrite, quartz, minor arsenopyrite.	Very similar to 47; appears weakly mineralized.
49	Unnamed (75Ast1974)	None recorded	N. 20°-40° W.-trending vertical vein 2 m thick.	Arsenopyrite, pyrite, quartz, some calcite gangue.	Small prospect pit discloses only weak mineralization.
50	Unnamed	None recorded	NE-trending quartz sulfide in graphitic quartzite of Pkg unit.	Pyrite; trace galena in quartz.	Caved pit; weak mineralization exposed.
51	McGonnigill	One ton shipped to testing plant in Seattle, circa, 1920 yielded 1.45 oz gold. (Davis, 1922, p. 131).	N. 58° E., 34° NW.-dipping vein 2-1/2 m thick; about 100 m of strike length of surface; cuts Psg unit.	Arsenopyrite, boulangerite, pyrite; minor galena and sphalerite in quartz-calcite gangue.	Selected ore has high gold assays.

Prospect	Name(s)	Production	Structure, geologic description	Mineralogy	Remarks
52	Glenn (Capps, 1916; Wells, 1933)	None recorded	N. 80°-85° E.-trending nearly vertical vein up to 3 m thick, 250 m of mineralized strike length; intrudes Psg unit.	Arsenopyrite, pyrite, galena, sphalerite, jamesonite, boulangerite; K-spar-quartz gangue.	Tunnels driven from 1906 to 1909 disclosed extensive mineralization; 60 vertical m of sulfide-bearing vein tunnels caved.
53	Glenn Ridge 1 (Wells, 1931) or Skookona prospect(s) (Capps, 1916).	None recorded	Large N. 20°-40° W.-trending vein system 1.2-10 m thick; dips 65° SW., 200-300 m exposed strike length.	Arsenopyrite, pyrite, scheelite(?), scorodite, quartz.	Entire ridge is resistant quartz vein-shear zone; potential for large, low-grade gold deposit. Mineralization on surface is not pronounced; should be explored.
54	Pension(?) claim (75Ast 1973)	None recorded	NW-trending vein in metafelsite schist, Psf unit.	Arsenopyrite, boulangerite, scorodite in quartz gangue.	Earlier assays showed strong silver assays; shaft and drift caved.
55	Arkansas claim	None recorded	N. 70° E. vertical vein 0.3-1.2 m thick; 50 m of strike on surface; intrudes Psf unit.	Arsenopyrite, boulangerite, jamesonite, pyrite, and minor galena in quartz gangue.	Exposures of mineralized vein offset left laterally along three small faults (pl. 3).
56	Lloyd prospect	None recorded	Quartzite band 1-3 m thick in chloritic greenstone schist (Psf unit) traceable for 50 m.	Chalcopyrite, sphalerite, and magnetite.	Apparently a premetamorphic sulfide occurrence with bands of sulfides folded with country rock; small adit 15 m long.
57	Unnamed (75Ast 2018-2019)	None recorded	N. 25°-45° E.-trending, 1-m-thick, intrudes pCs unit.	Siderite, boulangerite, pyrite, and quartz.	Small weakly mineralized vein, on the surface; unexplored.
58	Unnamed	None recorded	Poorly exposed vein deposit.	Arsenopyrite, quartz, minor galena.	Adit driven in 1912 is now caved.
59a	Rainy Creek Ridge 1	None recorded	N. 75°-85° E.-trending, silicified zone 1-5 m thick; traced for 800 m of discontinuous strike length.	Pyrite, quartz, stibnite, minor galena.	Impressive strike length of low-grade mineralization.

Prospect	Name(s)	Production	Structure, geologic description	Mineralogy	Remarks
59b	Rainy Creek Ridge 2	None recorded	N. 60°-75° E.-trending near-vertical silicified zone 5 m wide in saddle.	Arsenopyrite and quartz, with minor pyrite and kaolinite.	Impressive show of massive arsenopyrite mineralization in large shear zone; unexplored.
60	Lena and Silver Wire	None recorded	N. 60°-70° E.-trending 80° SE.-dipping vein, 1.5 m thick; poorly exposed on surface.	Galena-tetrahedrite-pyrite-quartz system.	Silver Wire showed good silver values in earlier years; apparently has discontinuous mineralization along strike.
61	Humbolt	"Several hundred pounds shipped to Fairbanks yielded good returns of free gold" (Capps, 1916, p. 99)	N. 55° E.-trending vertical quartz vein 1 m thick.	Pyrite, pyrrhotite, galena, quartz, sphalerite, minor arsenopyrite.	Tunnel 15 m long driven into vein (Capps, 1916, p. 99). Wells (1933) reports that ore contains mainly galena and sphalerite.
62	Ridge-Top claim (Davis, 1927, p. 133) or Spruce Creek #1 (Wells, 1931, p. 374).	None recorded	Quartz vein about 2.5 m thick cuts porphyroblastic schist and phyllite (Psf unit) N. 65° E., 22° NW. trend.	Pyrite, quartz, minor sphalerite(?) and galena; some copper carbonate.	Two shallow pits dug on vein are caved; traceable 50 m in talus.
63a	Home Lode (Wells, 1931)	None recorded	Vein deposit.	Stibnite-quartz.	Approximate location; not visited.
63b	Caribou lode or Last Chance deposit	About 75 tons selected high-grade stibnite ores and concentrates.	N. 15°-20° E.-trending, 50° NW.-dipping vein 1-2 m thick; taped for strike distance of 180 m (pl. 3).	Stibnite, pyrrhotite, jamesonite, pyrite; quartz gangue carries some gold.	Mining active recently (1975); small concentrator and 15-30 tons of ore on mine sight. Potential for small-scale future mineral production. Hawley (1977) detected significant gold in his samples.
64	Unnamed 75Ast1861	None recorded	Poorly exposed N. 20°-50° E.-trending strike of vein; 30 m of traceable material intrudes pCs unit.	Pyrite, quartz, extensive limonite stain.	Weakly mineralized on surface.

TABLE 9 (Continued)

Prospect	Name(s)	Production	Structure, geologic description	Mineralogy	Remarks
65	Mammoth Claim (Capps, 1916, p. 99; Lucky Jim(?), Davis, 1922, p. 132)	None recorded	N. 40° E. silicified zone, poorly exposed.	Quartz, pyrite, minor galena and chalcopyrite.	Free gold reported from this prospect. Poorly exposed vein.
66a,b	Unnamed (75Ast1881)	None recorded	Stratiform NE-trending silicified gossan zone in graphite schist (Psg unit) about 2 m wide, 80 m long, subparallel to schistocity.	Pyrite, quartz, feldspar, vanadinite(?), limonitic gossan.	Extensive limonitic gossan contains iron sulfides. Large strike length; stratiform(?) sulfide.
66c	Unnamed (75Ast1882, 1884)	None recorded	N. 50°-60° E. siliceous zone in metavolcanic schist of Psf unit, abundant pyrite.	Pyrite, quartz.	Extensive limonite gossan-developed stratiform pyrite mineralization in metavolcanic rock.
67	Unnamed (75Ast3061)	None recorded	0.67-m-thick vein intrudes Pkmg unit.	Stibnite, galena, sphalerite, quartz.	New prospect, unexplored. Surface showings are small.
68	Unnamed (75Ast2922)	None recorded	Sulfide zone 1.2-2 m thick in pCg unit; parallel to foliation (stratiform sulfides).	Pyrite, chalcopyrite, malachite, azurite.	Disseminated sulfide bands in greenstone schists.
69	Unnamed (75Ast1914)	None recorded	NE-trending vein swarm 5-10 m thick at least 110 m of strike length.	Major pyrite and quartz, minor galena.	Low-grade mineralization, previously unreported deposit.
70a	Moonlight-stibnite (Tosdal antimony)	None recorded	N. 30° E.-trending, 20° NW.-dipping sulfide-gash vein 25 cm thick subparallel to foliation; 2 m of exposure.	Massive stibnite, minor quartz.	Previously unreported antimony occurrence appears small; area could be explored for vein extensions; prominent depression 30 m beyond exposure.
70b	Unnamed (75Ast2824)	None recorded	Small N. 10° E., 20° SE.-dipping fracture in calcareous schist.	Limonite, minor galena; quartz gangue.	Small fracture in schist mineralized near dike swarm.
71	Unnamed; Canyon Creek occurrence	None recorded	NE-trending gabbro(?) dike is pyritized.	Limonite, pyrite, trace stibnite(?).	Small mineralized dike.

TABLE 9 (Continued)

Prospect	Name(s)	Production	Structure, geologic description	Mineralogy	Remarks
72a	Unnamed (75Ast1558)	None recorded	Small 0.3-m-thick quartz vein subparallel to schistocity of graphitic schist; very discontinuous.	Disseminated chalcopyrite, pyrite, minor malachite stain.	Unreported copper occurrence in vein SW of Stampede, small showing; contains copper, zinc, silver.
72b	Unnamed (75Ast1540)	None recorded	Quartzite veins with quartz, abundant limonite-trending zone N. 35° E. and dipping 45° SE. for 100 m.	Pyrite, limonite.	Large silicified zone contains antimony.
73	Stampede Mine (includes Glory, Surface, Hole, Emil Winze, and Mooney ore bodies)	3,590 tons of high-grade ores and concentrates that averaged 56% Sb.	Large, crosscutting NE-trending veins-fractures controlled by Stampede fault. Several hundred meters of mineralized strike length.	Major stibnite, quartz, minor pyrite-pyrrhotite-sphalerite, gold values in pyrite of vein and in schist.	Stampede vein system still holds economic-grade ore. Defense Minerals Exploration Administration project drilled underground and intersected two high-grade shoots, which have never been developed. Hawley (1977) estimates a reserve of about 10 million pounds Sb remains in deposits.
74	Kobuk lode	170 tons high-grade stibnite ore.	N. 74° E. nearly vertical vein-fault slivers in 'Stampede Quartzite'; individual veins 10-40 cm thick.	Stibnite, pyrite, boulangerite, pyrrhotite, and quartz.	Northeasterly extension of Stampede vein-fault system (pros. 73; see text).
75	'Clearwater Barite' (75Ast2548)	None recorded	N. 5° W., 40° SW.-dipping vein 1 m wide intrudes pCs(?) unit.	Barite, pyrite, quartz, and pyrrhotite.	Poorly exposed barite-sulfide occurrence.
76a	Upper-Ridge claims	None recorded	N. 10°-35° W. fracture system contains stibnite mineralization in approximately 100-sq-m area; intrudes quartz area.	Stibnite, limonite, and quartz.	Low-grade antimony mineralization.
76b	Nessie deposit	2,400 lb high-grade stibnite ore (1942).	Small stringers of crudely banded stibnite parallel to foliation in muscovite schist with N. 65° E., 20° NW. trend.	Stibnite, quartz, sphalerite, and pyrite.	Possible stratiform antimony mineralization is small.

Prospect	Name(s)	Production	Structure, geologic description	Mineralogy	Remarks
77a	Little Caribou prospect	None recorded	Contact metamorphic deposit in carbonate skarn, 1-1.5 m wide on surface, 180 m long; erratic mineralization; no intrusive exposed.	Pyrite, chalcopyrite, magnetite, ilmenite(?), epidote, sphalerite(?), tourmaline, massive hematite.	Sporadic sulfide shows on surface do not appear extensive; up to 0.3% zinc with anomalous lead, silver, copper; stream sediments below hill show strong zinc anomalies; needs detailed geochemical-geophysical work.
77b	Unnamed; 'Stibnite-Caribou'	None recorded	Lenses of stibnite in graphitic schist-marble unit.	Stibnite, pyrite.	
78	Unnamed	None recorded	Irregular pods of skarn in hornfels zone.	Magnetite, pyrite, sphalerite, and galena in limestone tactite.	Poorly exposed; low-grade mineralization.
79	'Crooked Creek prospect'	None recorded	Small, stratiform barite lenses and dissemination in metarhyolite.	Barite, quartz.	Low-grade barite.
80a	Gossan 1	None recorded	Heavily pyritized metavolcanic gossan zone 0.5 to 1 km wide and up to 8 km long; primary sulfide occurrence.	Major pyrite with local exsolved blebs of sphalerite in pyrite (polished section).	Volcanic zones constitute large, low-grade zinc deposits.
80b	Gossan 2	None recorded	Same as 80a	Same as 80a	Same as 80a.
81	Gossan 3	None recorded	Same as 80a	Same as 80a	Same as 80a.
82	Quartz lode 1 (75Ast1754)	None recorded	N. 40° W.-trending, 70° SW.-dipping vein system in massive outcrop of Totatlanika metarhyolite (Mtr); vein <1 m thick, trends up cliff face.	Chalcopyrite, galena, malachite and quartz.	Appears low grade.
83	Unnamed (75Ast1714)	None recorded	N. 20°-40° W.-trending vertical vein system 0.3-1.0 m wide in Totatlanika rhyolite (Mtr); 80 m of gossan on slope.	Galena, sphalerite, extensive limonitic boxwork structure; minor cerussite.	Appears low grade as above.

TABLE 9 (Continued)

Prospect	Name(s)	Production	Structure, geologic description	Mineralogy	Remarks
84	Chitsia zone (75Ast1735)	None	Silicified gossan zone near contact between Mts and Mtr units; float indicates 5 m wide; several hundred m in strike length.	Barite, quartz, galena, pyrite, minor sphalerite.	Barite-pyrite vein 100 m west of gossan.
85a	Unnamed (75Ast2765)	None	Gossan zone subparallel to strike of unit in Mtr unit, similar to occurrences 70-72; could be related to low-angle fault zone.	Pyrite, limonite, minor chalcopyrite.	Previously unreported occurrence.
85b	Unnamed (75Ast2771)	None	N. 20°-50° W. vertical vein in Mts unit.	Quartz, calcite, pyrite, minor chalcopyrite.	Previously unreported occurrence.
86	Unnamed (75Ast2794)	None	Pockets of limonite in siliceous phyllite (Mts) below metarhyolite flow rocks.	Limonite with anomalous lead, zinc, and silver values (table 10).	Previously unreported lead-zinc stratiform(?) mineralization on same stratigraphic horizon as Pros. 84.
87	Unnamed (75Ast1785)	None	N. 55° E.-trending, 55° SE.-dipping complex vein swarm pentrates Mtr plug; some veins are slightly mineralized.	Disseminated galena and limonite in quartz.	Low grade, but illustrates mineralized nature of large areas of silicified Mtr unit.

Table 10. Compiled assay values for lode mines and prospects from the Kantishna Hills, Alaska. DGGS analyses by atomic-absorption spectrophotometry[a]

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton)	Au (oz/ton)	Mo (ppm)	Sb (%)	W (ppm)	As (%)	Ba (%)	U (ppm)	Th (ppm)	Remarks
1	Bundtzen and others (1976) with additional data from this study	0.008	0.18	0.019	0.16	Trace	ND	17.14	<75	0.301	0.007	0.20	0.3	Average chip sample, ore in open cut.
		0.005	0.07	0.019	0.06	Trace	28	23.0	<75	2.80	0.008	1.4	4.0	Grab sample from open cut.
		0.006	0.045	0.024	0.04	0.01	ND	19.0	<75	3.19	0.005	0.6	3.3	Average chip sample of schist on dump.
		0.029	0.36	0.036	0.14	Trace		25.9	<75	0.3	0.007	0.2	0.7	Chip sample from exposed stibnite vein.
		0.005	0.07	0.002	0.04	Trace	41	40.8	<75	0.15	0.004	0.2	0.3	Grab sample from open cut.
		0.002	0.006	0.001	Trace	Trace	6	12.0	—	—	—	—	—	Chip sample from exposed sulfide vein in open cut.
		0.008	0.086	0.035	0.09	Trace	306	32.6	<75	1.46	0.005	0.6	1.3	Grab sample from dump.
2	This study	0.019	1.18	0.16	12.1	Trace	51	0.63	<75	0.40	.023	2.2	11.3	Grab sample of weathered gossan from open cut.
3						No assay information								
4	Bundtzen and others (1976) with additional data from this study	0.018	10.3	4.8	19.2	Trace	65	.60	<75	0.086	0.0002	2.3	0.5	Channel samples across 65 cm of sulfide vein in third adit (pl. 3).
		0.05	20.3	15.2	37.9	Trace	34	1.23	<75	0.058	0.0007	2.4	0.5	
		0.05	10.0	5.1	22.7	Trace	86	1.57	<75	0.085	0.0001	3.5	1.3	
		0.06	0.84	34.0	8.2	Trace	26	0.40	<75	0.109	0.0003	3.5	0.3	
	Saunders (1964)	—	—	—	11.9	Trace	—	—	—	—	—	—	—	Grab samples.
	Morrison (1964)	—	—	—	11.1	0.04	—	—	—	—	—	—	—	Grab samples.
		—	—	—	44.96	0.04	—	—	—	—	—	—	—	Grab samples.
	Seraphim (1960)	—	—	—	17.2	Trace	—	—	—	—	—	—	—	Grab sample, 8 in. vein, Neversweat, 30%

[a]ND = not detected; (—) = not analyzed; anomalous concentrations underlined.

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton)	Au (oz/ton)
		—	—	—	32.72	0.02
		—	—	—	Trace	Trace
		—	—	—	0.64	0.04
		—	—	—	14.04	Trace
	Wells (1933)	—	55.0	—	74.0	0.48
	U.S. Bureau Mines (1959, unpub.)	3.5	27.2	—	35.05	0.04
		0.06	16.0	7.04	15.39	0.02
		0.10	8.3	9.10	22.43	0.02
		0.05	4.3	24.20	2.47	0.02
		0.03	2.2	1.45	0.76	0.24
		0.21	32.9	5.15	14.40	0.01
5	This study	0.0001	0.0008	0.002	0.305	Trace
		0.0001	0.0002	0.001	Trace	Trace
6	Bundtzen and others (1976) and this study	0.01	0.06	0.02	1.74	Trace
7	Bundtzen and others (1976)	0.006	0.31	0.01	0.21	0.07

TABLE 10 (Continued)

Mo (ppm)	Sb (%)	W (ppm)	As (%)	Ba (%)	U (ppm)	Th (ppm)	Remarks
--	--	--	--	--	--	--	Sulfide, (third adit) 50% sulfide in porphyry.
--	--	--	--	--	--	--	1-m channel, footwall of vein, 1.9-m channel.
--	--	--	--	--	--	--	Neversweat tunnel, (third adit) 25% sulfide grab from caved cut.
--	--	--	--	--	--	--	Across Eldorado Creek from Neversweat.
--	--	--	--	--	--	--	"Sample of ore" (Wells, 1933, p. 376).
--	5.45	--	0.02	--	--	--	Grab sample from float.
--	0.51	--	0.11	--	--	--	Grab sample from float.
--	11.51	--	0.02	--	--	--	Grab sample, shipping ore.
--	0.94	--	0.16	--	--	--	Grab sample, zinc-ore pile.
--	1.01	--	2.06	--	--	--	Grab sample, jamesonite-stibnite pile.
--	3.97	--	0.11	--	--	--	Sample from face of Busia adit.
13	0.0002	--	--	--	--	--	Altered intrusive rubble with vein gossan.
8	ND	--	--	--	--	--	Altered intrusive rubble with vein gossan.
59	28.5	150	0.021	0.007	0.4	4.0	Chip sample across vein.
39	46.5	<75	0.23	0.002	ND	3.3	Grab of high grade from pit.

TABLE 10 (Continued)

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton	Au (oz/ton)	Mo (ppm)	Sb (%)	W (ppm)	As (%)	Ba (%)	U (ppm)	Th (ppm)	Remarks
8	This study	0.02	0.001	0.001	0.04	ND	69	—	—	—	—	—	—	Grab sample of gossan in pit.
9	Bundtzen and others (1976) and this study	0.10	2.02	5.88	17.50	Trace	18	1.22	<75	0.90	0.004	2.8	0.5	Grab samples from caved trenching.
		0.50	15.40	1.05	20.20	Trace	5	9.30	<75	2.65	0.001	3.2	0.6	
		0.94	18.70	2.89	83.82	Trace	4	8.52	<75	0.54	0.006	11.0	1.5	
		0.57	8.65	2.75	62.70	Trace	ND	4.36	ND	ND	0.003	20.0	3.0	
	Wells (1933)	—	5.46	—	374.20	0.01	—	—	—	—	—	—	—	10 tons averaged 200 oz Ag/ton (Wells, 1933).
	Seraphim (1960)	1) 0.88	8.90	—	63.60	0.04	—	—	—	—	—	—	—	1) Grab of mineralization on Alpha dump; 2) grab of mineralization near Alpha tunnel.
		2) 1.21	3.52	—	128.48	0.04	—	—	—	—	—	—	—	
	Hawley (1977)	0.23	6.50	1.25	12.90	Trace	—	0.86	—	—	—	—	—	3-m channel in caved portion; Alpha trench.
		0.08	1.15	0.75	9.40	Trace	—	0.29	—	—	—	—	—	
		0.50	18.50	4.65	23.50	Trace	—	2.78	—	—	—	—	—	
10	This study	0.004	0.001	0.033	Trace	Trace	41	0.006	—	—	—	—	—	Grab sample of limonitic gossan.
11	Hawley (1977)	—	3.8	0.195	2.20	0.035	—	—	—	—	—	—	—	Grab samples from trenches and dump.
		—	12.0	0.3550	14.11	0.070	—	—	—	—	—	—	—	
12	Hawley (1977)	Trace	0.055	0.031	0.082	Trace	—	—	—	—	—	—	—	Gossan analysis; no visible sulfides.
13	Bundtzen (1976) and this study	0.002	0.003	0.001	0.81	ND	65	14.1	<75	0.003	0.01	1.1	1.0	Grab sample of stibnite mineralization.
14	This study	0.021	0.023	0.021	0.02	ND	4	0.019	<75	0.005	0.015	3.6	3.3	Grab sample of stratiform show; chips from exposed mineralization contain arsenopyrite.
		0.043	0.025	0.32	0.10	ND	ND	0.002	125	0.242	0.018	0.7	4.0	
		0.006	0.008	0.013	0.03	ND	29	0.009	<75	0.009	0.017	3.3	6.3	

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton)	Au (oz/ton)
15	Bundtzen and others (1976) and this study	0.005	0.01	0.047	0.12	Trace
16	This study	0.044	0.004	0.008	0.01	ND
		0.004	0.001	0.004	0.01	ND
	Morrison (1964)	—	—	—	1.0	—
	Hawley (1977)	0.002	0.002	0.012	Trace	ND
17	Bundtzen and others (1976) and this study	0.009	0.274	0.012	0.91	0.047
	Hawley (1977)	0.003	1.05	2.95	0.25	ND
18	Bundtzen and others (1976)	0.001	0.039	0.026	0.05	ND
	Hawley (1977)	Trace	0.05	0.031	0.08	ND
19	Wells (1933)	—	26.0	—	214.0	0.90
		—	2.0	ND	325.1	2.53
		—	50.6	9.5	128.0	0.22
	Seraphim (1961)	0.08	40.57	—	119.06	0.24
	U.S. Bureau Mines (1959, (unpub.)	0.41	6.0	0.79	87.67	0.63
		0.49	0.43	8.21	58.42	0.32
		0.26	0.88	14.4	62.71	0.36

Mo (ppm)	Sb (%)	W (ppm)	As (%)	Ba (%)	U (ppm)	Th (ppm)	Remarks
6	0.004	<75	0.926	0.005	1.5	4.5	Chip sample of well exposed vein; contains visible arsenopyrite.
105	Trace	<75	0.017	0.003	2.4	5.5	Random grab samples
40	Trace	<75	0.003	0.008	2.8	2.8	pyrite rich; samples lamped (UV) but no scheelite.
--	--	--	--	--	--	--	
--	0.004	--	--	--	--	--	Contains 1000 ppm manganese.
32	51.5	<75	0.695	0.01	ND	0.5	Arsenic-rich stibnite contains gold-silver values.
--	0.17	--	--	--	--	--	Sulfide-bearing carbonate grab sample.
10	0.002	--	--	--	--	--	Caved pit sampled.
--	ND	--	--	--	--	--	Caved pit, reddish stain.
--	--	--	--	--	--	--	Average, 102 tons of ore shipped in 1922.
--	1.6	--	4.6	--	--	--	Richest ore assay.
--	0.6	--	2.5	--	--	--	Poorest ore assay.
--	--	--	--	--	--	--	Red-Top dump; 50% sulfide.
--	0.50	100	6.79	--	--	--	Sulfides from 1959 dump.
--	0.29	100	7.28	--	--	--	Dump above Red Top Portal.
--	0.36	100	3.74	--	--	--	From caved shaft above portal.

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton)
	Hawley (1977)	—	0.034	0.04	0.34
	Seraphim (1961)	0.88	14.49	—	152.90
20	This study	0.135	2.11	5.7	61.76
		0.31	1.98	6.6	26.1
		0.52	1.76	11.8	26.7
	Seraphim (1961)	0.24	5.49	—	51.48
	U.S. Bureau Mines (1959)	0.47	16.5	5.42	92.47
		0.34	0.06	0.05	69.51
21	Wells (1933)	—	—	—	6.4
	Hawley (1977)	ND	0.08	0.06	0.23
22	Davis (1922) a)	—	—	—	60.0
	Wells (1933) b)				
	c)	—	—	—	284.2
	U.S. Bureau Mines (1959) d)	0.10	51.8	4.05	74.96
	Wells (1933)	—	—	—	2.20
23	Davis (1922) a)	—	—	—	0.45
	Seraphim (1961)	0.08	3.73	—	16.44
	Hawley (1977) b)	0.12	0.28	0.14	14.1

Au (oz/ton)	Mo (ppm)	Sb (%)	W (ppm)	As (%)	Ba (%)	U (ppm)	Th (ppm)	Remarks
0.48	—	—	—	—	—	—	—	West of portal along vein contains 64 ppm Hg.
0.20	—	—	—	—	—	—	—	Silver-King shaft.
0.06	ND	0.19	—	6.39	0.001	1.1	0.5	High-grade grab samples.
0.04	ND	0.16	—	—	—	0.7	2.3	
0.045	ND	0.10	—	5.21	0.003	3.2	0.8	
0.18	—	—	—	—	—	—	—	Grab mineralization, Galena dump.
0.24	—	0.47	100	1.46	—	—	—	At portal, caved adit.
0.03	—	10.93	100	ND	—	—	—	Grab sample, dump.
0.04	—	—	—	—	—	—	—	High-grade sample.
0.03	ND	—	—	—	—	—	—	Soil sample east of portal.
—	—	—	—	—	—	—	—	Galena-rich stringer.
No assay information								
0.08	—	—	—	—	—	—	—	6-in. channel, average vein.
0.60	—	0.36	—	0.02	—	—	—	Free gold and galena panned from crushed ore (Davis, 1922, p. 125).
0.12	—	—	—	—	—	—	—	No base-metal data.
0.022	—	—	—	—	—	—	—	Average of 4 samples.
0.36	—	—	—	—	—	—	—	1-ft channel.
0.31	—	0.12	—	—	—	—	—	Near Silver-Pick claim.

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton)
	U.S. Bureau Mines (1959)	—	1.55	63.7	524.24
24	Seraphim (1961)	0.24	1.04	—	144.14
		0.48	9.93	—	133.92
		0.24	3.31	—	89.28
	Davis (1922)	—	—	—	5.70
		—	—	—	37.6
	This study	0.189	2.48	1.25	44.4
25	Davis (1922)	—	—	—	160.0
	Seraphim (1961)	0.10	15.11	—	73.04
	This study	0.245	1.6	0.050	16.26
		0.231	2.15	0.057	49.7
26	Hawley (1977)	—	0.36	0.25	2.79
		—	0.26	0.16	1.50
		—	0.04	0.05	11.03
		—	0.03	2.65	0.25
		—	0.13	0.58	0.5
		—	0.18	2.20	47.06
		—	0.08	0.62	0.26
	Conwell (1974)	0.098	5.9	4.8	35.00
	This study	0.25	7.2	10.5	39.70
		0.25	5.48	5.0	0.15

TABLE 10 (Continued)

Au (oz/ton)	Mo (ppm)	Sb (%)	W (ppm)	As (%)	Ba (%)	U (ppm)	Th (ppm)	Remarks
0.12	--	1.84	--	--	--	--	--	Channel, Little Maud.
0.56	--	--	--	--	--	--	--	20-in. channel.
0.12	--	--	--	--	--	--	--	Grab sample high grade.
1.22	--	--	--	--	--	--	--	18-in. channel.
0.03	--	--	--	--	--	--	--	Tunnel sample.
0.11	--	--	--	--	--	--	--	Average of 6 samples.
0.01	3	0.19	--	0.28	0.009	0.7	0.5	High-grade sample contains tetrahedrite.
--	--	--	--	--	--	--	--	Average grade, 4 tons of ore.
0.32	--	--	--	--	--	--	--	Channel-cut sample.
0.03	ND	0.48	--	--	--	5.7	0.3	High grade, sulfide rich.
0.02	--	0.55	--	--	--	1.2	0.8	
0.19	--	--	--	--	--	--	--	Channel cross section of
0.34	--	--	--	--	--	--	--	vein underground.
0.44	--	--	--	--	--	--	--	
0.01	--	--	--	--	--	--	--	
0.06	--	--	--	--	--	--	--	
0.08	--	--	--	--	--	--	--	
0.05	--	--	--	--	--	--	--	
0.245	--	--	--	--	--	--	--	Mill heads of 120 tons mined in 1973.
0.08	60	0.08	75	2.08	0.04	0.1	1.8	Grab sample.
0.15	31	0.06	75	0.73	0.004	0.4	0.3	

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton)	Au (oz/ton)	Mo (ppm)	Sb (%)	W (ppm)	As (%)	Ba (%)	U (ppm)	Th (ppm)	Remarks
	Seraphim (1961)	0.32	35.18	—	159.58	0.20	—	—	—	—	—	—	—	Grab sample.
		0.90	4.6	37.7	140.87	0.18	—	0.90	—	—	—	—	—	
	U.S. Bureau Mines	0.11	11.0	5.55	62.09	0.11	—	0.47	—	—	—	—	—	Grab sample.
27[b]	Wells (1933)	—	25.0	—	175.0	0.16	—	—	—	—	—	—	—	Assay of 438.6 tons shipped in 1920.
	Bundtzen and others (1976)	0.17	2.7	0.28	19.0	Trace	8	0.16	75	0.462	ND	0.7	2.5	Grabs of sulfide ore from dump.
		0.18	1.86	1.57	18.9	0.06	51	0.05	1100	0.90	0.01	0.7	0.3	
		0.031	0.014	0.38	0.88	0.01	91	0.02	7400	0.80	0.003	0.6	0.2	
	U.S. Bureau Mines (1959)	1.55	36.3	1.56	396.03	0.21	—	1.59	—	—	—	—	—	Grab samples high grade.
		0.26	24.0	0.79	80.74	0.19	—	0.70	—	—	—	—	—	
	Seraphim (1961)	0.08	70.38	—	148.42	0.08	—	—	—	—	—	—	—	Galena specimen, upper Little Annie.
		0.16	7.04	—	11.98	0.12	—	—	—	—	—	—	—	Main Little-Annie vein.
	Davis (1922)	—	48.7	—	286.20	0.26	—	—	—	—	—	—	—	Full width of 'galena' vein sampled underground.
		—	26.10	—	224.00	0.22	—	—	—	—	—	—	—	
		—	46.7	—	243.8	0.54	—	—	—	—	—	—	—	
		—	53.4	—	218.9	0.14	—	—	—	—	—	—	—	
		—	—	—	136.50	0.08	—	—	—	—	—	—	—	Little Annie No. 2 grab sample of 'solid galena.'
28	This study	0.018	0.086	0.025	1.07	0.05	ND	0.005	—	0.016	0.004	5.6	6.5	Grab sample disseminated mineralization.
29	Hawley (1977)	—	Trace	—	1.61	—	—	0.68	—	—	—	—	—	Contain 0.15 ppm Hg.
30	U.S. Bureau Mines (1959)	0.10	0.03	0.11	0.11	Trace	—	0.01	400	0.04	—	—	—	1.4-ft channel sample; iron-stained quartz.
		0.52	2.22	6.00	43.13	0.02	—	0.18	100	0.42	—	—	—	Sulfide-rich grab sample.

[b]Does not include 57 gold-silver assays reported by Wells (1933).

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton)	Au (oz/ton)	Mo (ppm)	Sb (%)	W (ppm)	As (%)	Ba (%)	U (ppm)	Th (ppm)	Remarks
		0.26	3.60	4.89	3.60	Trace	--	0.01	100	0.14	--	--	--	Steel galena, pyrite, arsenopyrite(?), and tetrahedrite(?).
	Davis (1922)	--	--	--	1.60	--	--	--	--	--	--	--	--	Channel across 18-in. of
		--	--	--	0.20	0.86	--	--	--	--	--	--	--	vein near old shaft.
	Hawley (1977)	0.008	0.027	0.04	0.35	0.12	--	--	--	--	--	--	--	Soil of gossan on Pennsylvania claim.
31	Seraphim (1961)	0.08	16.97	--	4.88	0.02	--	--	--	--	--	--	--	Float on White-Hawk claim.
		--	--	--	0.90	0.06	--	--	--	--	--	--	--	Boulangerite-rich grab sample.
32	Hawley (1977)	0.006	0.33	0.52	0.76	0.035	--	0.14	--	--	--	--	--	Gossan-soil on claim.
		Trace	0.001	0.0005	0.01	0.04	--	ND	--	--	--	--	--	Quartz-vein float.
		0.003	0.003	0.08	0.08	0.09	--	ND	--	--	--	--	--	Old prospect pit quartz vein.
	Seraphim (1961)	0.24	1.24	--	76.68	0.02	--	--	--	--	--	--	--	Float on water-level claim.
	Davis (1922)	--	--	--	30.40	--	--	--	--	--	--	--	--	Reported assay mainly in boulangerite.
33	Seraphim (1961)	--	--	--	0.22	0.06	--	--	--	--	--	--	--	Float; sulfide claim.
	Hawley (1977)	0.001	0.001	0.001	0.08	0.10	--	ND	--	--	--	--	--	Quartz gossan.
34	Hawley (1977)	--	6.90	9.25	70.5	0.64	--	--	--	--	--	--	--	Merry-Widow claim.
	Bundtzen and others (1976)	0.09	5.70	2.50	12.7	0.02	8	0.004	<75	0.86	0.01	3.3	4.8	Random grab, limonite gossan.
		0.23	8.6	7.5	55.47	0.02	39	0.18	<75	0.168	0.03	1.4	3.8	Channel sample across 1 m of gossan.

TABLE 10 (Continued)

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton)	Au (oz/ton)	Mo (ppm)	Sb (%)	W (ppm)	As (%)	Bi (%)	U (ppm)	Th (ppm)	Remarks
35	This study	0.015	0.013	0.002	0.03	0.044	6	12	—	14.2	ND	2.1	1.0	Grab sample from dump.
	Bundtzen and others (1976)	—	—	—	0.52	0.46	—	—	—	—	—	—	—	Average grade of 13,656 tons of ore.
	Hawley (1977)	ND	0.245	0.075	2.94	0.058	—	ND	—	—	—	—	—	Grab sample; tailings.
36	This study	0.18	0.27	0.05	3.76	0.20	ND	0.023	—	14.2	0.012	—	0.8	Grab samples; high grade.
		0.06	0.63	0.12	14.6	0.20	ND	0.025	—	—	0.018	7.2	22.5	
	Hawley (1977)	0.25	2.25	0.46	7.64	0.16	—	—	—	—	—	—	—	Channel sample underground,
		0.095	1.60	0.18	2.94	0.044	—	0.034	—	—	—	—	—	see plate 3.
		0.029	0.023	0.18	0.035	Trace	—	0.003	—	—	—	—	—	Same.
37	Hawley (1977)	0.007	0.011	0.037	0.03	Trace	—	ND	—	—	—	—	—	Soil samples across
		0.002	0.013	0.026	0.26	Trace	—	ND	—	—	—	—	—	mineralized zone.
		0.007	0.11	0.06	0.47	0.01	—	ND	—	—	—	—	—	
		0.01	0.39	0.08	0.64	0.01	—	ND	—	—	—	—	—	
38	This study	0.005	0.17	0.005	0.14	ND	9	0.01	<75	0.035	0.009	1.3	3.5	Grab sample from pit, low-
		Trace	0.03	0.02	0.22	Trace	ND	ND	<75	0.028	0.046	0.8	2.0	grade mineralization.
		0.006	0.01	0.016	0.04	ND	35	0.002	<75	0.029	0.051	1.1	2.9	
39	This study	1.5	4.55	1.25	39.4	ND	ND	2.35	<75	0.076	0.003	2.7	1.8	Grab sample of copper-rich
		1.4	46.3	1.1	29.1	Trace	15	2.87	—	—	—	—	—	galena ore.
	U.S. Bureau Mines (1959)	1.58	70.0	1.49	54.42	Trace	ND	3.10	—	—	—	—	—	Grab sample, galena ore.
	Hawley (1977)	1.35	50.0	5.2	33.82	Trace	ND	0.88	—	—	—	—	—	Massive galena ore.
40	Bundtzen and others (1976)	0.003	0.02	0.04	Trace	Trace	75	0.049	<75	0.37	0.002	ND	0.8	Arsenopyrite vein poorly exposed.

TABLE 10 (Continued)

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton)	Au (oz/ton)	Mo (ppm)	Sb (%)	W (ppm)	As (%)	Ba (%)	U (ppm)	Th (ppm)	Remarks
41	Hawley (1977)	0.046	2.75	1.15	1.47	ND	ND	0.35	—	—	—	--	--	Sulfide grab sample.
	This study	0.88	32.8	20.4	26.4	Trace	1	1.36	<75	0.027	0.009	1.3	1.8	Grab sample, high-grade galena.
42	This study	0.34	76.0	1.56	71.7	Trace	ND	0.94	<75	0.023	0.001	0.5	1.3	Massive galena.
		6.66	24.5	0.38	223.3	.02	40	1.54	<75	0.51	0.008	1.0	1.0	Massive galena ore.
	Hawley (1977)	0.10	5.0	8.63	44.1	Trace	--	0.54	--	--	--	--	--	Galena ore contains 32 ppm Hg.
43a	This study	0.002	0.001	0.001	0.01	0.03	19	0.014	--	—	--	—	--	Arsenopyrite-quartz float.
43b	This study	0.006	0.015	0.24	0.01	Trace	22	0.81	<75	0.048	0.016	3.2	5.5	Disseminated boulangerite in quartz.
44	Bundtzen and others (1976) and this study	0.050	48.3	0.072	5.0	0.02	6	0.10	—	--	--	--	--	Massive galena.
		0.077	52.0	0.133	79.1	0.04	50	0.38	<75	4.97	0.001	5.2	1.5	Massive galena.
	Hawley (1977)	ND	0.35	0.057	0.56	Trace	—	—	--	—	—	—	--	Grab samples; mineralization, contains 0.06 ppm Hg.
		—	0.057	0.09	0.164	0.04	—	--	—	—	—	—	--	
		—	0.003	0.265	0.02	Trace	—	--	—	—	—	—	--	
45	This study	0.03	3.83	0.01	13.7	2.99	100	0.05	—	—	—	—	—	High-grade chip samples.
		0.102	0.019	4.0	0.28	Trace	6	0.099	—	—	—	—	—	
		0.80	1.9	1.47	36.0	0.1123	44	0.82	—	—	—	—	—	Channel samples across vein.
		1.05	7.9	2.65	223.1	0.104	41	1.16	—	—	—	—	—	
		0.205	0.56	2.44	27.5	0.048	4	0.10	—	—	—	—	—	
		0.072	0.027	0.76	1.26	0.008	18	0.008	—	—	—	—	—	
		1.00	22.0	3.10	243.5	0.087	49	1.26	—	—	—	—	—	High grade.
45b	Hawley (1977)	ND	0.023	0.051	Trace	Trace	—	0.001	—	—	—	—	—	0.03 ppm Hg; near Eureka location; Hawley reports anomalous soil samples here.

TABLE 10 (Continued)

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton)	Au (oz/ton)	Mo (ppm)	Sb (%)	W (ppm)	As (%)	Ba (%)	U (ppm)	Th (ppm)	Remarks
46	This study	0.004	0.005	0.003	0.10	0.11	8	0.004	<75	1.37	0.001	0.1	1.8	Arsenopyrite-quartz grab sample.
	Hawley (1977)	ND	0.022	0.012	0.09	0.01	—	ND	<75	—	—	—	—	Pit samples.
		—	0.012	0.010	0.05	0.01	—	ND	—	—	—	—	—	
47	This study	0.005	0.018	0.008	0.09	0.01	20	0.001	<75	0.572	0.007	1.0	4.3	Grab samples; pyrite ore.
	Hawley (1977)	0.001	0.003	0.013	ND	ND	—	ND	—	—	—	—	—	Gossan chip.
48	This study	0.002	0.004	0.002	0.01	Trace	8	ND	<75	0.017	0.008	0.9	4.0	Grab sample, pyrite schist.
	Hawley (1977)	ND	0.024	0.021	0.01	Trace	—	ND	—	—	—	—	—	0.06 ppm Hg.
49	This study	0.005	0.004	0.001	ND	ND	14	ND	—	—	—	—	—	Gossanized chips.
		0.02	Trace	0.03	0.02	Trace	100	0.01	—	—	—	—	—	
50	This study	0.004	0.042	0.003	0.114	0.01	21	Trace	<75	0.016	0.003	0.1	1.0	Pyrite and trace galena in quartz.
51	This study	0.007	2.20	0.45	1.35	0.11	54	1.13	<75	6.28	0.038	0.8	4.8	Arsenopyrite, galena, and
		0.005	0.68	0.52	0.87	0.03	39	0.58	<75	8.51	0.008	0.4	1.5	boulangerite in quartz.
		—	—	—	0.25	0.17	—	—	—	—	—	—	—	Grab sample.
		—	—	—	2.24	0.24	—	—	—	—	—	—	—	1-ft channel area.
	Davis (1922)	—	—	—	52.0	—	—	—	—	—	—	—	—	
		—	—	—	63.0	0.60	—	—	—	—	—	—	—	
52	This study	0.008	1.38	0.045	2.32	0.02	16	0.94	—	—	—	—	—	Grab samples, weathered sulfides.
		0.05	7.20	0.02	5.40	0.01	100	3.36	<75	0.532	0.006	0.1	1.0	Same.
		—	—	—	0.76	0.04	—	—	—	—	—	—	—	Grab sample, dumps.
53	Seraphim (1961)	—	—	—	2.14	0.08	—	—	—	—	—	—	—	

TABLE 10 (Continued)

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton)	Au (oz/ton)	Mo (ppm)	Sb (%)	W (ppm)	As (%)	Ba (%)	U (ppm)	Th (ppm)	Remarks
	This study	0.009	0.20	0.36	0.04	0.04	45	0.007	—	—	—	—	—	Chip samples from mineralized pods in large quartz shear zone.
		0.014	0.78	0.072	16.4	0.28	31	0.10	150	8.32	0.004	2.0	2.5	
		0.004	0.73	0.017	3.3	0.03	71	0.022	—	—	—	—	—	
		0.004	0.24	0.24	6.14	0.02	53	0.405	<75	1.54	0.018	3.2	0.3	
		0.004	0.35	0.31	6.17	0.03	25	0.089	—	—	—	—	—	
		—	—	0.72	25.5	0.08	8	0.24	—	—	—	—	—	
		—	—	0.36	1.0	0.026	38	0.02	—	—	—	—	—	
		0.01	—	0.079	7.1	0.01	62	0.14	—	—	—	—	—	Grab sample.
	Hawley (1977)	Trace	0.15	0.10	0.76	0.04	—	—	—	—	—	—	—	Massive quartz vein.
54	This study	0.007	2.76	0.40	1.27	0.16	16	1.05	<75	0.34	0.009	0.7	1.8	Arsenopyrite and boulangerite in quartz.
	Davis (1922)	—	—	—	150.0	—	—	—	—	—	—	—	—	2-1/2-ft-galena vein.
55	Bundtzen and others (1976) and this study	0.006	0.71	0.14	1.36	0.08	60	0.74	<75	5.97	0.018	0.6	0.3	Chip sample contains boulangerite, pyrite, and arsenopyrite in quartz.
	Davis (1922)	—	—	—	90.0	—	—	—	—	—	—	—	—	Sulfides in quartz band in schist.
56	Bundtzen and others (1976) and this study	2.16	0.09	3.98	0.97	0.01	43	0.001	<75	ND	0.001	0.4	1.3	High-grade sulfide zone.
57	Bundtzen and others (1976)	0.054	3.5	2.6	9.37	Trace	85	1.19	<75	0.04	0.005	3.8	4.5	High-grade sample of low-grade mineralization.
58						No assay information								
59a	Bundtzen and others (1976)	0.003	0.136	0.031	0.45	Trace	63	0.23	—	—	0.035	9.4	5.5	Random grab sample with sulfide.

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton)	Au (oz/ton)	Mo (ppm)	Sb (%)	W (ppm)	As (%)	Ba (%)	U (ppm)	Th (ppm)	Remarks
	This study	0.009	0.38	0.043	1.79	0.01	5	0.42	75	2.53	0.026	1.5	8.0	Chip samples, over 500 m
		0.001	0.012	0.002	0.02	Trace	4	0.025	75	0.026	0.018	1.3	6.0	of strike.
		0.002	0.001	0.002	ND	ND	10	0.004	75	0.032	0.14	1.3	1.3	
59b	This study	0.003	0.046	0.007	0.23	ND	13	0.046	75	2.86	0.029	1.7	8.0	Arsenopyrite in siliceous
		0.002	0.005	0.002	0.01	Trace	8	0.001	--	--	--	--	--	schist.
		0.011	0.31	0.042	0.13	0.01	1	0.25	75	11.00	0.007	0.2	1.8	
60	Wells (1931)	--	--	--	75.0	0.50	--	--	--	--	--	--	--	Silver-bearing galena ore described by Wells (1931).
61	Hawley (1977)	0.067	1.45	2.10	3.52	0.01	--	--	--	--	--	--	--	Soil gossan.
62	This study	0.003	0.008	0.003	0.235	0.02	86	0.01	--	--	0.015	ND	1.5	Grab samples of quartz
		0.003	0.011	0.003	0.335	0.225	32	0.002	--	--	0.014	9.7	14.3	vein.
		0.001	0.046	0.006	0.282	0.10	3	ND	--	--	--	--	--	
		0.001	0.003	0.002	0.01	0.01	3	0.001	--	--	--	--	--	
		0.001	0.001	0.003	Trace	Trace	0.14	ND	--	--	--	--	--	
	Hawley (1977)	0.048	1.05	0.70	2.64	0.04	--	--	--	--	--	--	--	Soil sample.
63a						No assay information								
63b	This study	0.011	0.005	0.021	0.07	0.146	1	0.021	--	--	--	--	--	Mineralized quartz vein
		0.006	0.015	0.106	0.04	0.05	69	6.75	--	--	--	--	--	intrudes amphibolite-quartz
		0.011	0.04	0.016	0.01	0.01	18	26.0	--	--	--	--	--	near open cut.
		0.004	0.004	0.061	0.04	0.01	ND	16.4	--	--	--	--	--	
		0.002	0.001	0.03	0.02	0.02	11	0.17	--	--	--	--	--	
		0.010	0.030	Trace	0.03	0.01	100	36.4	--	--	--	--	--	High grade from dump.
	Hawley (1977)	Trace	0.003	0.016	0.01	0.01	--	0.18	--	--	--	--	--	Chip samples in open cut.
		0.065	0.001	0.013	3.23	0.08	--	0.034	--	--	--	--	--	
		0.001	0.002	0.008	0.01	0.11	--	0.056	--	--	--	--	--	
		0.001	0.001	0.001	0.01	0.02	--	0.026	--	--	--	--	--	

TABLE 10 (Continued)

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton)	Au (oz/ton)	Mo (ppm)	Sb (%)	W (ppm)	As (%)	Ba (%)	U (ppm)	Th (ppm)	Remarks
64	This study	0.04	0.002	0.003	ND	ND	30	0.001	<75	0.002	0.006	12.0	5.0	Quartz vein with limonite.
		0.002	0.001	0.008	ND	ND	1	ND	--	--	--	--	--	Grab sample; pyrite rich.
		0.006	0.006	0.003	0.01	0.01	11	ND	--	--	--	--	--	
65	Hawley (1977)	0.001	0.007	0.008	0.04	0.02	--	Trace	--	--	--	--	--	Pyrite quartzite; gossan
		0.005	0.002	0.003	Trace	Trace	--	Trace	--	--	--	--	--	soils.
	This study	0.001	0.001	0.001	0.02	Trace	15	0.002	--	--	--	--	--	Pyrite in felsic schist.
66a	Hawley (1977)	0.032	0.035	1.70	0.10	Trace	--	Trace	--	--	--	--	--	Gossan layer in graphite schist.
66b	This study	Trace	0.105	0.024	0.05	Trace	--	--	--	--	--	--	--	Weak pyrite mineralization
		0.002	0.003	0.007	Trace	Trace	7	10	--	--	--	--	--	in metavolcanic schist.
66c	This study	0.002	0.003	0.006	Trace	Trace	27	ND	--	--	--	--	--	Weak pyrite mineralization
		0.001	0.002	0.021	Trace	ND	5	0.001	--	--	--	--	--	in metavolcanic schist.
		0.004	0.001	0.002	Trace	ND	ND	0.001	--	--	--	--	--	
67	Bundtzen and	0.38	2.10	14.74	48.5	0.10	45	0.50	<75	2.15	0.003	0.2	3.3	Grab samples, sulfide
	others (1976),	0.002	0.005	0.009	Trace	Trace	42	ND	<75	0.009	0.029	0.0	3.5	zone.
	this study	0.30	1.43	0.20	0.14	0.22	Trace	0.02	--	--	--	--	--	
68	Bundtzen and others (1976)	0.035	0.001	0.004	ND	ND	44	ND	<75	0.004	0.011	3.2	15.3	Sulfide in schist.
	This study	1.02	Trace	0.003	0.02	Trace	18	Trace	<75	0.001	0.021	2.4	1.5	Cu-stained schist.
		0.012	0.69	0.60	0.91	Trace	24	0.002	<75	0.003	0.001	1.2	5.8	Sulfides in fracture in schist.
69		0.004	0.105	0.024	0.05	Trace	11	0.002	<75	0.006	0.032	0.6	6.0	Grab sample, mineraliza-
		0.03	0.47	0.14	0.25	Trace	10	0.003	<75	0.008	0.034	2.4	6.5	tion.
		0.01	0.18	0.08	0.05	Trace	44	0.023	--	--	0.017	5.8	5.0	
70a	Bundtzen and others (1976)	0.005	0.01	0.014	ND	0.01	ND	1.19	<75	0.93	0.104	3.1	28.0	Gossan; stibnite.

TABLE 10 (Continued)

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton)	Au (oz/ton)	Mo (ppm)	Sb (%)	W (ppm)	As (%)	Ba (%)	U (ppm)	Th (ppm)	Remarks
	This study	0.014	0.14	0.012	Trace	Trace	ND	65.5	—	—	—	—	—	High-grade massive stibnite.
		0.014	0.74	0.028	0.33	ND	2	64.0	—	—	—	—	—	
70b	This study	0.007	1.15	0.001	0.62	ND	16	0.001	<75	0.002	0.003	1.0	1.0	Vein deposit with disseminated galena-limonite pocket in quartz.
71	This study	0.006	0.005	0.004	0.10	0.01	—	0.016	—	—	—	0.5	4.3	Pyritiferrous grab sample of gabbro(?) dike.
72a	Bundtzen and others (1976)	0.04	0.03	0.01	1.28	Trace	Trace	Trace	—	—	—	—	—	Grab samples malachite-stained quartz schist.
	This study	0.024	0.002	0.038	1.15	Trace	81	0.003	—	—	0.027	18.4	2.8	Grab samples.
		0.011	0.001	0.043	0.03	Trace	67	0.003	—	—	—	—	—	Grab samples.
		0.016	0.001	0.030	0.02	ND	100	0.01	—	—	—	—	—	Grab samples.
72b	This study	0.002	0.002	0.002	ND	Trace	51	0.052	—	—	—	—	—	Gossan chips in fracture.
73	This study	0.008	0.039	0.072	0.138	0.116	60	25.3	<75	2.00	0.003	0.2	0.5	Random grab samples; high-grade ore, surface ore body.
		0.011	0.055	0.015	0.09	Trace	59	47.8	<75	0.176	0.004	ND	1.8	
		0.002	0.015	0.001	0.05	0.028	54	26.2	<75	0.29	0.033	1.3	5.0	
		0.011	0.031	0.032	0.21	0.06	70	14.5	<75	0.96	0.02	2.3	1.2	
	Analyzed twice for gold a)	0.001	0.002	0.001	0.07	0.045	20	0.493	—	—	0.463	2.3	22.3	Chip samples across surface ore body and wall rock of vein.
	b)	0.004	0.002	0.004	0.08	0.295	20	3.26	—	—	—	6.9	15.0	
	c)	0.005	0.007	0.003	0.176	0.215	24	3.08	—	—	0.349	4.4	20.0	
	d)	0.003	0.004	0.004	0.08	0.057	8	1.74	—	—	0.314	6.2	16.8	
74	Hawley (1977)	—	—	ND	Trace	Trace	—	0.082	—	—	—	—	—	Channel sample across approximately 20 m of vein and gossans.
		—	—	ND	Trace	Trace	—	0.042	—	—	—	—	—	
		—	—	ND	Trace	Trace	—	0.005	—	—	—	—	—	
		—	—	ND	Trace	Trace	—	0.021	—	—	—	—	—	
		—	—	ND	0.105	0.01	—	2.75	—	—	—	—	—	
		—	—	ND	0.04	0.02	—	1.2	—	—	—	—	—	
		—	—	ND	0.02	0.01	—	0.36	—	—	—	—	—	
		—	—	ND	0.01	Trace	—	1.7	—	—	—	—	—	
		—	—	ND	ND	ND	—	0.035	—	—	—	—	—	

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton)	Au (oz/ton)	Mo (ppm)	Sb (%)	W (ppm)	As (%)	Ba (%)	U (ppm)	Th (ppm)	Remarks
	Bundtzen and	Trace	0.01	Trace	0.05	0.02	Trace	26.2	—	—	—	—	—	Grab samples along road
	others (1976);	Trace	Trace	Trace	0.17	0.23	Trace	30.8	—	—	—	—	—	cut.
	this study													
75	This study	0.001	0.008	0.017	ND	Trace	ND	0.002	—	—	—	—	—	Contains approximately 25% barite.
76a	This study	0.003	0.001	0.001	0.308	0.01	33	0.80	—	—	—	—	—	Disseminated sulfide gashes
		0.001	0.001	Trace	0.01	Trace	50	0.016	—	—	—	—	—	(stibnite) in quartzite.
76b	Bundtzen and	0.026	0.03	1.20	0.01	Trace	19	0.031	—	—	—	—	—	Sulfide schist near vein.
	others (1976)	0.01	0.03	0.03	0.20	0.06	22	14.5	—	—	—	—	—	Stibnite gash vein.
77a	Bundtzen and others (1976)	0.011	0.003	0.028	0.01	0.03	24	0.002	—	—	—	—	—	In marble lens 300 m east of main showing.
		0.002	0.035	0.15	Trace	ND	37	0.001	—	—	—	—	—	Main skarn zone.
		Trace	0.10	0.37	0.17	0.01	Trace	Trace	—	—	—	—	—	Main skarn zone.
		0.01	Trace	0.03	0.01	0.03	Trace	Trace	—	—	—	—	—	
77b	Hawley (1977)	—	—	—	0.16	Trace	—	0.27	—	—	—	—	—	Grab sample; additional soil traverse not reported here.
78	This study	0.006	0.067	0.132	0.03	ND	ND	Trace	<75	0.004	0.019	(3.9)	(8.0)	Grab samples of sulfide
												(4.1)	(6.3)	skarn.
		0.01	0.023	0.188	ND	ND	3	0.001	<75	ND	0.018	(2.5	(9.5)	
												(3.2)	(10.5)	
79	This study,	0.011	0.007	0.012	0.04	Trace	7	0.001	125	0.016	0.23	1.8	2.5	Grab samples with visible
	Gilbert and	0.01	0.01	0.011	Trace	Trace	11	0.001	<75	0.022	1.83	0.3	2.5	barite.
	Bundtzen (1979)													
80a	Bundtzen and	0.01	0.02	0.16	0.02	Trace	6	ND	—	—	0.095	10.2	16.3	Random samples; altered
	others (1976),	0.002	0.037	0.003	0.06	ND	35	0.001	<75	0.023	0.151	5.3	16.8	gossan, metavolcanic rocks.
	Gilbert and	0.003	0.006	0.009	ND	ND	17	ND	<75	0.004	0.167	5.5	19.8	
	Bundtzen (1979)	0.003	0.012	0.02	0.02	Trace	24	Trace	—	—	—	—	—	

TABLE 10 (Continued)

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton)	Au (oz/ton)	Mo (ppm)	Sb (%)	W (ppm)	As (%)	Ba (%)	U (ppm)	Th (ppm)	Remarks
		0.004	0.001	0.05	0.01	Trace	17	Trace	—	—	—	—	—	
		0.002	0.004	0.006	0.01	0.01	25	Trace	<75	0.007	0.081	5.5	35.3	
		0.001	0.002	0.008	Trace	ND	39	ND	<75	0.003	0.064	5.8	16.3	
		0.002	0.005	0.005	ND	ND	47	ND	<75	0.005	0.126	4.0	14.8	
	Hawley (1977)	—	—	0.005	Trace	—	—	—	—	—	—	—	—	Gossan; extensive soil samples not reported here.
80b	Bundtzen and	Trace	Trace	0.52	0.01	Trace	Trace	Trace	—	—	—	—	—	
	others (1976),	Trace	0.06	0.16	0.03	Trace	Trace	0.01	—	—	—	—	—	
	this study	0.005	0.004	0.466	Trace	ND	20	ND	—	—	1.45	<u>30.8</u>	9.8	
81	Bundtzen and	0.01	0.012	0.22	0.1	ND	9	ND	—	—	0.389	12.9	16.8	Grab samples, pyritic meta-
	others (1976),	0.002	0.007	0.011	ND	ND	10	Trace	—	—	—	—	—	andesite.
	Gilbert and	0.004	0.007	0.29	ND	ND	10	ND	—	—	0.162	<u>44.2</u>	18.3	
	Bundtzen (1979)	0.004	0.042	0.028	0.02	ND	18	Trace	—	—	—	—	—	Hawley (1977) reports ex-
		0.005	0.012	0.009	0.01	Trace	<u>330</u>	0.059	—	—	—	—	—	tensive soil anomalies.
82	This study,	1.00	0.012	0.006	0.24	ND	29	ND	—	—	—	—	—	Sulfide-rich grab samples;
	Bundtzen and	0.58	0.021	0.004	0.12	ND	21	Trace	—	—	—	—	—	vein in metarhyolite.
	others (1976)	0.65	0.01	0.005	0.14	ND	51	0.001	<75	0.005	0.010	2.0	4.5	
83	Bundtzen and	0.002	0.054	0.126	Trace	ND	8	ND	—	—	—	—	—	Grab samples; sulfide
	others (1976,	0.003	0.124	0.043	0.05	ND	12	ND	—	—	0.148	6.2	6.5	gossan.
	this study,	0.022	0.085	0.005	0.16	Trace	45	0.001	—	—	—	—	—	
	Gilbert and	0.011	10.50	0.016	2.73	ND	72	0.016	—	—	0.0128	<u>23.5</u>	2.5	
	Bundtzen	Trace	0.17	0.04	0.09	Trace	Trace	Trace	—	—	—	—	—	
	(1979)	0.03	3.10	0.24	1.17	0.02	8	0.006	—	—	0.244	6.7	14.5	
84	This study	0.001	0.02	0.106	0.02	Trace	ND	ND	—	—	—	—	—	Grab samples of stratiform
		0.003	0.052	0.002	0.09	ND	25	Trace	—	—	—	—	—	sulfide-barite lenses;
		0.003	0.120	0.021	0.18	Trace	19	0.004	—	—	—	—	—	massive barite not analyzed.
		0.003	0.027	0.002	0.24	Trace	17	Trace	<75	0.020	0.36	3.0	13.0	
		0.019	0.942	0.042	0.57	Trace	ND	0.003	—	—	4.46	(3.4)	(14.0)	
												(23.5)	(2.4)	
		0.002	0.054	0.017	0.31	Trace	50	0.019	—	—	—	—	—	

TABLE 10 (Continued)

Number	Source	Cu (%)	Pb (%)	Zn (%)	Ag (oz/ton)	Au (oz/ton)	Mo (ppm)	Sb (%)	W (ppm)	As (%)	Ba (%)	U (ppm)	Th (ppm)	Remarks
	Bundtzen and	0.001	0.062	0.069	0.04	Trace	7	0.011	—	—	—	—	—	
	Gilbert (1979)	0.010	0.120	0.04	0.06	ND	12	ND	—	—	0.14	6.2	6.5	
		0.010	0.05	0.15	0.06	Trace	28	0.009	—	—	0.367	1.8	13.0	
	Hawley (1977)	0.010	0.165	0.072	0.10	Trace	—	0.002	—	—	52.0	—	—	Selected grab samples.
		0.012	0.105	0.24	0.06	Trace	—	0.002	—	—	1.6	—	—	
		—	—	—	—	—	—	—	—	—	36.0	—	—	
85a	Bundtzen and	0.04	0.04	0.05	0.01	Trace	Trace	Trace	—	—	—	—	—	Pyritiferrous phyllite grab
	others (1976)	0.001	0.003	0.014	0.01	Trace	10	0.001	—	—	—	—	—	samples.
		0.005	0.007	0.03	0.01	Trace	6	ND	—	—	—	—	—	
85b	This study	0.01	0.01	0.01	0.96	0.09	100	0.45	—	—	—	—	—	
		0.04	0.041	0.036	0.01	ND	28	ND	<75	0.011	0.14	2.3	14.8	
86	This study	0.003	0.0127	0.015	Trace	ND	91	0.46	—	—	—	—	—	Gossanized phyllite schist
		0.029	0.057	0.16	0.05	ND	10	0.001	<75	0.017	0.53	2.3	4.3	in grab samples.
		0.019	0.40	0.15	0.18	ND	17	0.002	<75	0.075	0.13	4.2	5.5	
		0.006	0.13	0.08	0.09	ND	15	0.001	<75	0.021	0.18	3.2	4.3	
		0.078	0.20	0.17	0.24	Trace	5	0.007	<75	0.058	0.10	3.9	3.3	
87	This study	0.004	0.02	0.02	0.04	Trace	ND	ND	<75	ND	0.08	5.6	20.8	

TABLE 11

PRODUCTION OF ANTIMONY ORES, CONCENTRATES, STAMPEDE MINE

Year[1]	Ore + Concentrates (ton)	Antimony (%)	Antimony (lb.)
Pre-1937	150.0	---	---
1937	873.67	55.01	962,000
1938	426.73	52.00	444,000
1939	211.51	49.68	210,000
1940	293.83	52.16	306,000
1941	582.90	53.47	624,000
1942	80.0	52.0	83,200
1943	120.0	52.0	124,400
1944	78.5	50.0	78,500
1945	40.0	56.0	46,600
1946	40.0	56.0	44,800
1947	26.0	56.0	29,120
1948	68.5	56.0	69,720
1949	74.0	56.0	82,880
1951	121.0	56.0	135,520
1956	120.0	56.0	134,400
1957	63.5	56.0	71,120
1964	40.0	56.0	46,600
1965	40.0	56.0	46,600
1969	23.0	56.0	29,760
1970	121.35	56.0	126,209
Total	3,594.5		3,695,429

[1]From White (1942)
[2]Estimated by E.R. Pilgrim

Sources: White, 1942; E.R. Pilgrim, pers. commun.

PRODUCTION OF ANTIMONY FROM SOUTHERN PART, KANTISHNA MINERAL BELT

Area	Ore(ton)	Antimony (lb.)	Duration of Mining
Slate Creek		800,000	1916, 1942-49, 1970-71, 1979
Last Chance	71.5	74,360	1905,1968-70, 1973-74
Eureka Creek	~ 50	Unknown	~ 1915

Sources: Mining and Engineering Journal (1915), Joesting (1942, 1943), Mertie (1951), John Millhouse (oral commun., 1979).

TABLE 12

KNOWN PRODUCTION OF GOLD, SILVER, AND LEAD FROM THE BONANZA VEINS

QUIGLEY HILL AND VICINITY, KANTISHNA, ALASKA[1]

	Tons of Ore	Silver (oz.)	Gold (oz.)	Lead (lb.)	Years
Gold Dollar	638	76,120	159.5	273,160	1920, 1921, 1973
Little Annie	715	115,945	74.5	144,400	1919, 120
Little Annie (upper)	10	1,360	NA	4,000	1921
Red Top	184	43,664	187.3	93,200	1922, 1923
Galena	100	17,000	NA	NA	1920, 1921
Gold Eagle	4	680	NA	NA	1920
Marth Q	4	1,136	NA	NA	1920, 1921
Alpha	10	2,000	25.0	NA	1921
Total	1,655	257,965	449.0	504,760	

[1]Includes 120 tons of lower grade ore mined in 1973.

Sources: Davis (1923), Wells (1933), Morris (1939), L. M. Anthony (oral commun., 1978).

Table 13. Production figures, Banjo lode (Red Top Mining Company)[a]

Year	Tons of ore	Gold (oz) Amalgam recovery	Gold (oz) Sulfide concentrates	Silver (oz) Amalgam recovery	Silver (oz) Sulfide concentrates	Duration of mining
1939	3225	1073.3	127.7	664.5	341.0	May 1 - Oct 15
1940	4138	1980.6	534.9	1541.5	1385.7	May 24 - Nov 9
1941	6290	1772.4	771.0	1182.1	1999.0	May 10 - Oct 2
Subtotal		4826.3	1433.6	3388.1	3725.7	
Total		6259.9		7113.8		

Concentrate Assays

Year	Amount (lb)	Au (oz/ton)	Ag (oz/ton)	Pb (%)	Zn (%)	As (%)	Cu (%)
1939	13,208	19.6	52.3	--	--	--	0.15
1940	32,540	32.9	83.8	13.8	1.6	2.9	0.16
1941	43,214	35.6	92.5	19.7	0.9	4.75	0.13

[a]An unknown amount of ore was produced in 1938 as mill-test material and in 1942, before mine closure (Morris, 1939; E.R. Pilgrim, pers. commun., 1976).

TABLE 14

SULFIDE-GANGUE PARAGENESIS FROM VEIN-FAULTS IN THE KANTISHNA MINING DISTRICT[1]

Sulfide Minerals	Formula	Relative[3] Abundance	Ore Stages[2] 1	2	3	4	5
argyrodite	$AgSnS_6$	tr			1 tr		
arsenopyrite	FeAsS	m	3	20	4	1	
boulangerite	$5PbS \cdot 2Sb_2S_3$	tr			1		
chalcopyrite	$CuFeS_2$	M,m	1	8	4	6	1
covellite	CuS	m				5	6
galena	Pbs	M,m,tr		6	6	4	
gold	Au	tr	1	1			
jamesonite	$4Pbs \cdot FeS \cdot Sb_2S_3$	m			3	1	1
marcasite	FeS	m	1	1			
pearceite	$9Ag_2S \cdot As_2S_3$	m,tr			2		
polybasite	$9Ag_2S \cdot Sb_2S_3$	m,tr		1	4		
pyrargyrite	$3Ag_2S \cdot Sb_2S_3$	m,tr			2		
pyrite	FeS_2	M,m	3	21	3	1	
pyrrhotite	FeS	m		3	1	1	
sphalerite	(ZnFe)S	M,m	1	13	11	8	2
stephanite	$5Ag_2S \cdot Sb_2S_3$	tr			1		
stibnite	Sb_2S_3	M,m			1	10	
tetrahedrite[4]	$3Ca_2S \cdot Sb_2S_3$	M,m,tr		3	9	5	1
Gangue Minerals							
barite		m		1			
calcite		M,m	2	2			
chlorite		tr		3			
quartz		M	38	9	4	2	2
sericite		m,tr		3			
tourmaline		m,tr		2	2		
siderite		M,m	6	1	2		

[1]Based on examination of 52 polished sections and 10 thin sections using reflected and transmitted light respectively. Polished section identifications augmented by Vickers microhardness tester, assay data, reflectivity tests, and limited x-ray diffraction analysis.

[2]Number of observed species in sections.

[3]M = major m = minor tr = trace

[4]Includes freibergite and tennantite.

TABLE 15

PRINCIPAL MINERALS IN HYDROTHERMAL ORE DEPOSITS IN DIFFERENT TEMPERATURE ZONES; MODIFIED FROM LINDGREN (1932) AND KRAUSKOPF (1974)

Temperature and depth decreasing →

Hypothermal	Mesothermal	Epithermal
	Ore minerals	
Wolframite, $(Fe_2Mn)WO_4$	Chalcopyrite, $CuFeS_2$	Argentite, Ag_2S
Cassiterite, SnO_2	Bornite, Cu_5FeS_4	Silver, Ag
(Hematite, Fe_2O_3)	Tetrahedrite, $Cu_{12}Sb_4S_{13}$	Proustite, Ag_3AsS_3
Magnetite, Fe_3O_4	Enargite, Cu_3AsS_4	Pyrargyrite, Ag_3SbS_3
Arsenopyrite, FeAsS	Pyrite, FeS_2	Pyrite, FeS_2
Chalcopyrite, $CuFeS_2$	Galena, PbS	Marcasite, FeS_2
Gold, Au	Sphalerite, ZnS	Gold, Au
Molybdenite, MoS_2	Gold, Au	Cinnabar, HgS
Pyrrhotite, $Fe_{1-2}S$	Arsenopyrite, FeAsS	Stibnite, Sb_2S_3
(Bismuth, Bi)	(Argenite, Ag_2S)	(Galena, PbS)
(Galena, PbS)		(Sphalerite, ZnS)
(Sphalerite, ZnS)		(Chalcopyrite, $CuFeS_2$)
	Gangue minerals	
Quartz	Quartz	Quartz
Tourmaline	Carbonates	Adularia
Garnet	Barite	Chalcedony
Topaz		Opal
Micas		Fluorite
Apatite		Alunite
		Calcite

TABLE 16

LEAD ISOTOPIC ANALYSES OF GALENA SPECIMENS FROM THE KANTISHNA MINING DISTRICT, ALASKA
(Analyses by Teledyne Isotopes, Westward, New Jersey)

Deposit	Mineral Analyzed	Deposit Type	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Little Annie (Pros. 27, pl. 1)	galena	quartz-carbonate sulfide vein	1.344	25.541	21.007	52.108	19.000	15.630	38.763
Bosart (Pros. 42, pl. 1)	galena	massive sulfide vein	1.342	25.545	21.018	52.095	19.035	15.655	38.818

TABLE 17

AVERAGE STREAM GRADIENTS OF CREEKS AND TRIBUTARIES OF THE KANTISHNA MINING DISTRICT, ALASKA

Creek	Stream Gradient	U.S. Mint Gold Production Records[1]
Friday	80 m/km	104
Eureka	55 m/km	5,576
Glacier	45 m/km	1,154
Caribou	40 m/km	11,570
Little Moose	60 m/km	1,948
22-Pup	80 m/km	105
Canyon	160 m/km	--
Flat	140 m/km	--
Yellow	85 m/km	203
Rainy	110 m/km	--
Crooked	45-50 m/km	972
Glenn	55 m/km	2,250
Riddle (18) Gulch	165 m/km	48
Last Chance	85 m/km	665
Spruce	85 m/km	1,183

[1]Conservative and incomplete; does not include production since 1968.

TABLE 18

MINERALOGICAL IDENTIFICATION OF PANCONCENTRATES FROM THE KANTISHNA DISTRICT, ALASKA
(X-ray Diffraction Analyses by N. C. Veach, ADGGS)

Locality	Sample Type	Minerals Identified Major	Minerals Identified Minor
Spruce Creek	3 pan concentrates from placer cut	quartz galena cerusstite	sphalerite chalcopyrite stibnite
Glacier Creek	concentrates from sluice box, placer operation, 1975	quartz schist magnetite(18%) tremolite hornblende	pyrite rutile garnet ilmenite apatite zircon cassiterite stibnite scheelite(.01%) gold(.0034 gms)
Lower Caribou Creek	concentrates from 1975 washing plant	quartz mica feldspar magnetite garnet	ilmenite pyrite galena scheelite(.069%) rutile tourmaline zircon cassiterite(.01%) gold(.013 gms)
Glenn Creek	selected coarse tin concentrate	cassiterite rhodocrosite pyroxmangite	arsenopyrite jamesonite quartz
Moose Creek at mouth of Eldorado Creek	concentrate from 1975 placer operation	quartz hyperstene magnetite hornblende garnet ilmenite	fluorapatite olivine hematite pyrite galena fluorite bornite stibnite sphalerite chalcopyrite zircon tourmaline siderite scheelite

Table 18 (Continued)

Locality	Sample Type	Minerals Identified Major	Minor
Eureka Creek	1975 placer mine concentrates	magnetite(82%) pyrite galena garnet	tetrahedrite scheelite cassiterite hematite ilmenite pyrargyrite spodumene rutile tourmaline gold(136 gms)
Lower Moonlight Creek	composite analyses of five pan concentrates	quartz pyrite dolomite white/mica	siderite dolomite magnetite goethite
Upper Moonlight Creek	composite analyses of three pan concentrates	spessartite chlorite quartz pyroxene	zircon actinolite siderite magnetite anatase rutile dolomite

[1]major = > 10%
minor = < 10%

TABLE 19

GOLD FINENESS RESULTS, KANTISHNA DISTRICT, ALASKA

Creek	Gold	Silver	Number of Analyses	Gold Fineness Range	Source[1]
Caribou	679.6	319.0	11	568.0-747.0	Glover (1948)
	677.0	--	--	--	Metz & Hawkins (1981)
Eureka	791.9	--	11	747.0-840.9	Glover (1948)
	--	--	--	730.0-860.0	Smith (1941)
	906.0	--	--	--	Metz & Hawkins (1981)
Lower Eureka	771.0	221.0	3	765.0-779.0	Glover (1948)
22 Pup	777.5	--	2	--	Glover (1948)
	875.0	--	--	--	Metz & Hawkins (1981)
Glacier	759.4	--	5	734.3-783.0	Glover (1948)
	773.0	--	--	--	Metz & Hawkins (1981)
Crooked	850.2	--	14	841.0-872.0	Glover (1948)
	842.5	--	1	--	Smith (1941)
	881.0	--	--	--	Metz & Hawkins (1981)
Glenn	764.0	--	11	686.0-792.0	Glover (1948)
	896.0	--	--	--	Metz & Hawkins (1981)
Friday	760.6	203.0	5	735.0-795.0	Glover (1948)
	806.0	--	--	--	Metz & Hawkins (1981)
Eldorado	835.0	157.0	1	--	Glover (1948)
Moose	727.0	258.0	1	--	Glover (1948)
	812.0	--	--	--	Metz & Hawkins (1981)
Moose Bench	741.0	254.0	4	727.0-755.0	Glover (1948)
Yellow	733.0	255.0	4	724.0-756.0	Glover (1948)
	898.0	--	--	--	Metz & Hawkins (1981)
Crevice	729.0	260.0	1	--	Glover (1948)
Little Moose	564.1	--	9	541.0-572.0	Glover (1948)
	566.0	--	6	563.5-569.0	Smith (1941)
	550.0	--	--	--	Wimmler (1927)
	584.0	--	--	--	Metz & Hawkins (1981)
Stampede	544.4	--	2	525.0-564.6	Glover (1948)
	567.0	--	--	--	Metz & Hawkins (1981)

[1]Smith (1941) reported 18 analyses from the district that ranged from 720.5-860.0 and averaged 791.0. With the exception of Eureka Creek and Crooked Creek, he lumped his data. He treated Little Moose Creek separately as shown.

Plate I

HOLOCENE

Qht

Placer Mine Tailings; sorted boulder to cobble gravel piles with finer fraction artificially removed.

Qal

Stream Alluvium; silt, sa
deposited in modern stre
flora often present.

PLEISTOCENE

PLIOCENE

UPPER CRETACEOUS TO EOCENE

Tb,Tf,Tu,Thg

Dikes and Plugs; Tb=dar
grained, equigranular, olivi
Tf=light gray, porphyritic
Tu=altered ultramafic dike
gray, medium grained hor

SSISSIPPIAN

Mims

Mixed Metasedimentary Rocks; green

Mts

Metasandstone and Tuff;

EXPLANATION

Quaternary Deposits

Qal

Alluvium; silt, sand, and gravel in modern streams; pioneer n present.

Qaf

Alluvial Fan Deposits; coarse, stratified gravel and sand in both active and inactive fan systems.

Qu

Undifferentiated Quaternary D includes eolian and retransp and remnant glacial deposits

Qb

Terrace Alluvium; poorly stratified sand and gravel of several ages, generally covered with climax vegetation

$Qd_{1,2}$

Till; unconsolidated hummocky diamicton of early (1) and late (2) Wisconsinan age.

Tertiary Sedimentary Rocks

Ts

Nenana Gravel (?) poorly exposed and consolidated silt, sand, and gravel

Intrusive and Related Rock Units

Tb, Tf, Tu, Thd

Plugs; Tb=dark gray, fine quigranular, olivine augite basalt ray, porphyritic quartz felsite l ultramafic dike Thd=medium ium grained hornblende dacite

Th

Hornfels and Skarn; green-gray, aphanitic, dense, epidote, garnet, magnetite skarn and tremolite hornfels

Tgd

Granodiorite; medium gray, me grained, locally porphyritic intru of dominantly granodiorite in co

Tqr

Altered Rhyolite Sills; light gray to tan, propylitized, fine grained rhyolite sills. Forms resistant protruding outcrops.

Totatlanika Schist

Mts

Mtm

Mtr

^{40}K-^{40}Ar Age Determinat

(Bundtzen and Turne

Map Number	Rock Type
1	amphibolite dike
2	quartz mica schis
2	" " "
3	" " "
3	" " "
4	garnet amphiboli
5	amphibolite
6	garnet amphibol
7	metarhyolite
8	olivine gabbro
9	hornblende daci
10	olivine gabbro
11	quartz porphyr

Quaternary Deposits;
nd retransported silt,
cial deposits.

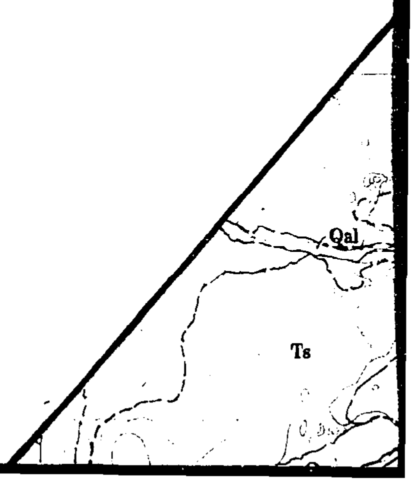
Qsl

Landslide Deposits; poorly sorted soil and rock colluvim derived from large scale slope failure.

Geology by T.K. Bundtzen 1975, 1976, 1978, 1979
R.M. Tosdal and T.E. Smith, 1975; J.E. Decker, J.T.
V.F. Ferrel, 1976; G.M. Laird, 1979. Airphoto In
of Quaternary Deposits by Bundtzen, 1980.

jd

dium gray, medium
rphyritic intrusive
nodiorite in composition



Mtr

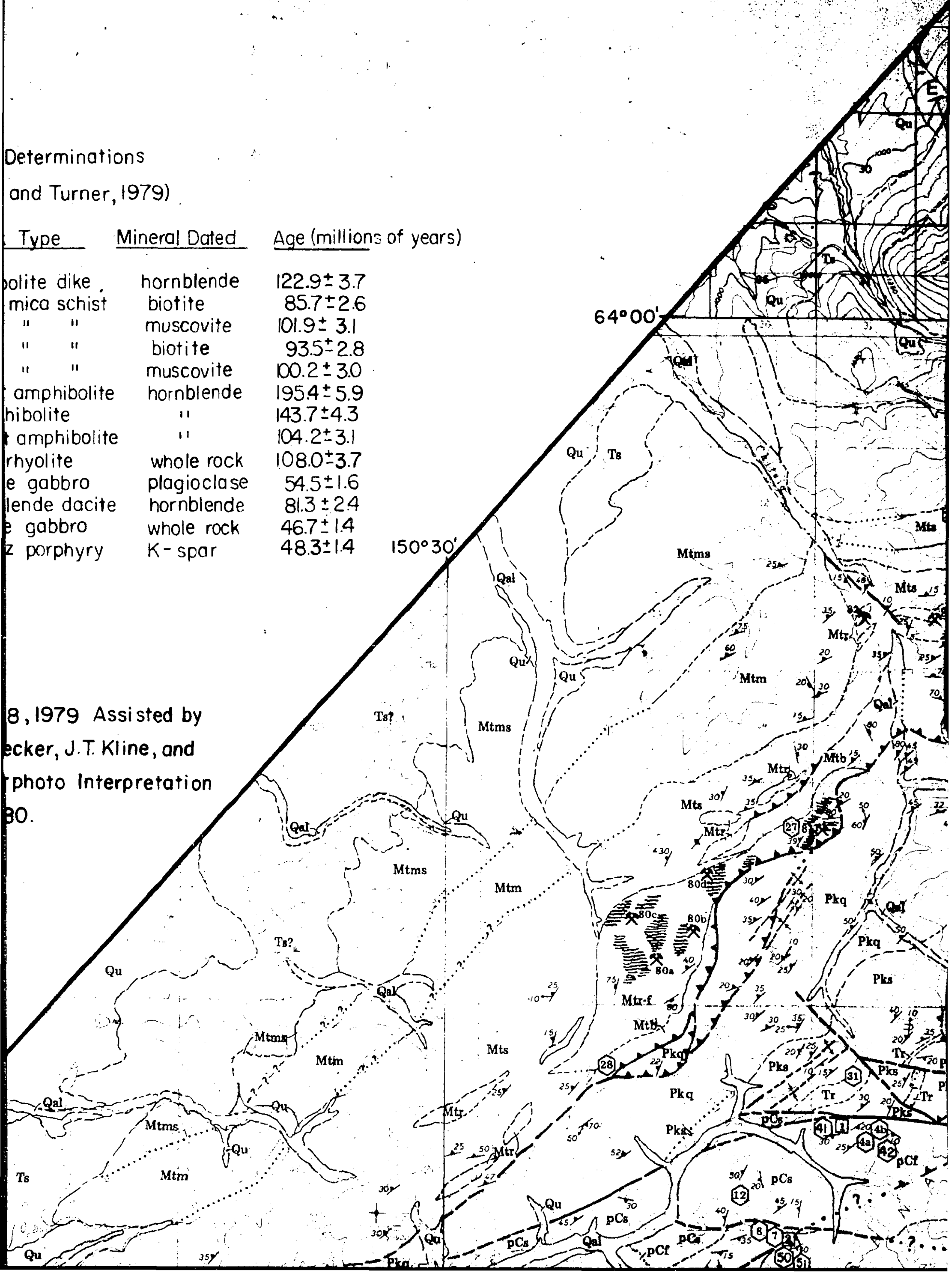
Mtb

Determinations

and Turner, 1979)

Type	Mineral Dated	Age (millions of years)
olite dike,	hornblende	122.9 ± 3.7
mica schist	biotite	85.7 ± 2.6
" "	muscovite	101.9 ± 3.1
" "	biotite	93.5 ± 2.8
" "	muscovite	100.2 ± 3.0
amphibolite	hornblende	195.4 ± 5.9
hibolite	"	143.7 ± 4.3
amphibolite	"	104.2 ± 3.1
rhyolite	whole rock	108.0 ± 3.7
e gabbro	plagioclase	54.5 ± 1.6
lende dacite	hornblende	81.3 ± 2.4
e gabbro	whole rock	46.7 ± 1.4
z porphyry	K-spar	48.3 ± 1.4

8, 1979 Assisted by
ecker, J.T. Kline, and
rphoto Interpretation
80.



PRECAMBRIAN TO LOWER PALEOZOIC

Mtms

Mixed Metasedimentary Rocks; green to gray, quartz rich metasandstone, marble, and greenstone. Generally nonresistant.

Mts

Metasandstone and Tuff; gr phyllite and greenish gray ch sandstone, contains minor

Pks

Calcareous Semischist; lig tan weathered, micaceous m calc-schist, containing abund and quartz veining. Nonresis friable.

Birch Creek

pCg

Greenstone and Greenschist; dark green, medium grained, schistose to massive, garnetiferous amphibolite. Locally includes biotite muscovite schist interbeds. Generally resistant.

pCs gr

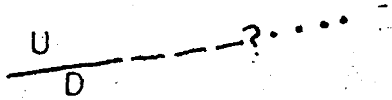
Undifferentiated Schist, Quartzite, and Gneiss; mixed unit of medium to coarse grained, garnetiferous quartz mica schist, massive to laminated quartzite, and feldspar biotite schist and gneiss. May include other metamorphic units.

pCgs

Graphitic Schist; dark gray, limonitically stained, complexly folded, graphitic schist. Forms nonresistant saddles.

Geologic Symbols

(Lined Symbols are Dashed Where Approximatel
Dotted Where Inferred or Concealed, Queried W



High Angle Fault; U= upthrown side
D= downthrown side; arrows indicate movement

Rock Contact

Totatlanika Schist

Mts

ıdstone and Tuff; green to maroon and greenish gray chloritic meta- ıe, contains minor greenstone.

Mtm

Marble; light gray, medium grained, micaceous marble; Resistant and forms folded outcrops.

Mtr

Metafelsite Porphyry and Serici gray-green, siliceous, sericite ric exhibiting blastoporphyritic text k-spar metafelsite and fine gr sericite schist. Very resistant rugged terrain.

Keevy Peak Formation

Pks

ous Semischist; light gray, hered, micaceous marble and ist, containing abundant calcite rtz veining. Nonresistant anc

Pkq

Black Quartzite, Slate and Marble; dark gray, fine grained to laminated, siliceous phyllite, and slate (85%) and marble (15%). Generally nonresistant.

Pkc

Metaconglomerate and Quartzit gray, siliceous unit with sheare up to 30 cm long. Contains min and marble.

Spruce Creek Sequence

Psf

Metafelsite and Chloritic Phyllite; light gray to green meta-igneous rocks; variably resistant.

Psg

Marble and Graphitic Phyllite; medium gray, mica rich, marble and folded phyllite. May include Psf or pC units. Generally nonresistant.

Creek Schist

gs

ist; dark gray, stained, com- graphitic schist. sistant saddles.

pCc

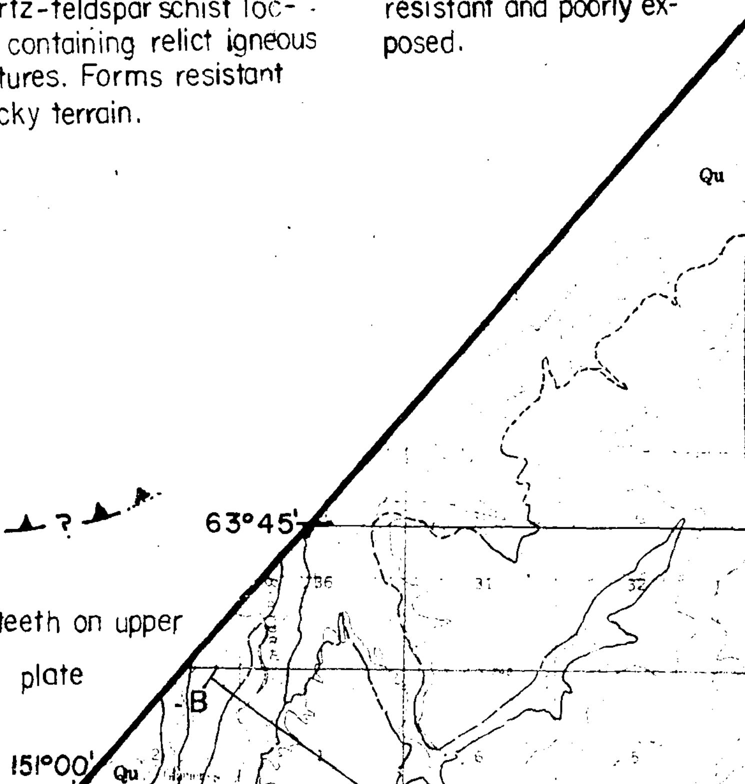
Calcareous Schist; medium gray, tan weathered, calcareous muscovite schist with interbedded marble and quartzite. Forms resistant knobs and hogbacks.

pCf

Quartz-Feldspar Schist and Gneiss; heterogeneous unit of tan to gray, garnetiferous quartz-feldspar schist locally containing relict igneous textures. Forms resistant blocky terrain.

pCm

Marble; light gray, medium grained, micaceous marble. Generally nonresistant and poorly exposed.



ymbols

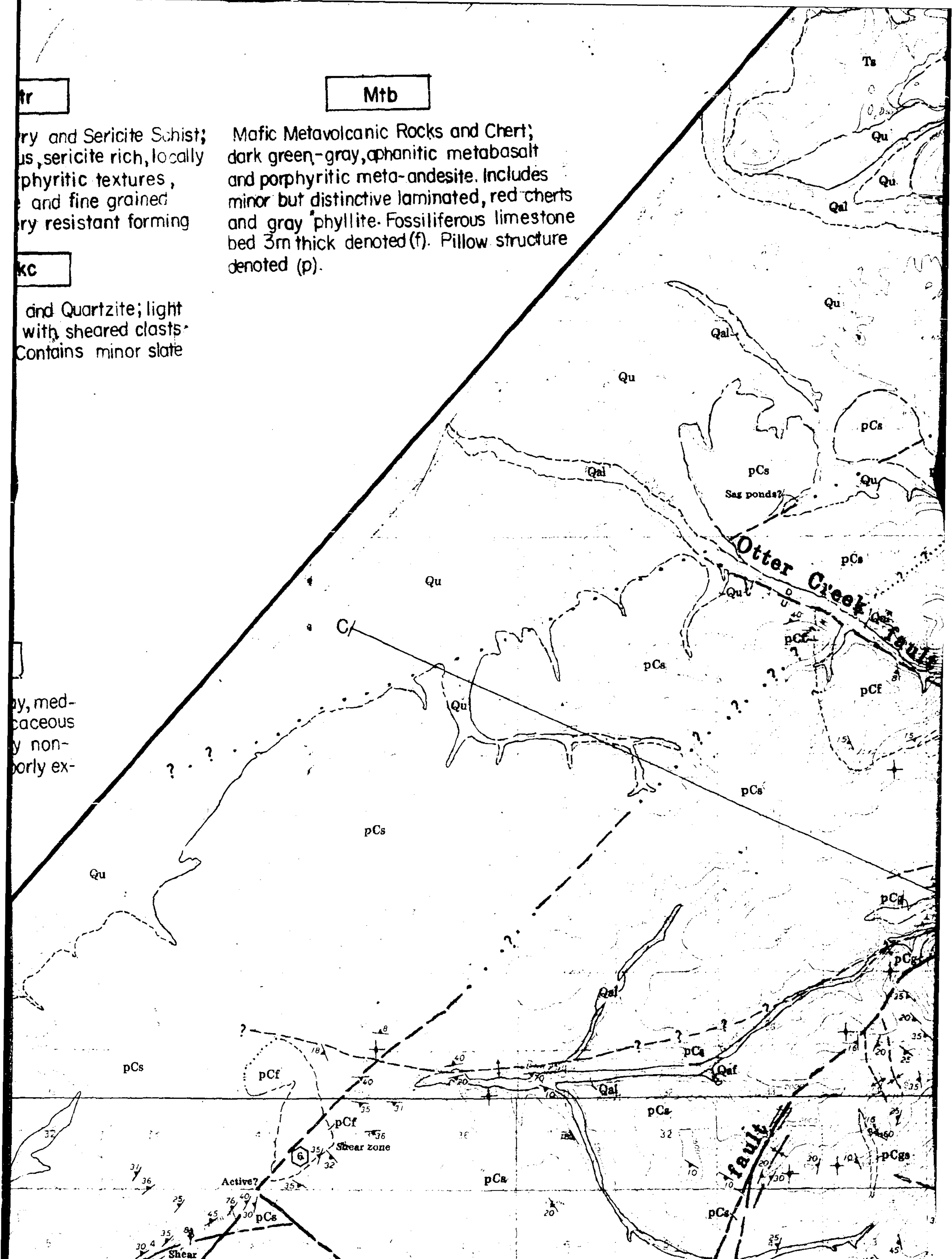
ere Approximately Located, ealed, Queried Where Doubtful)

?

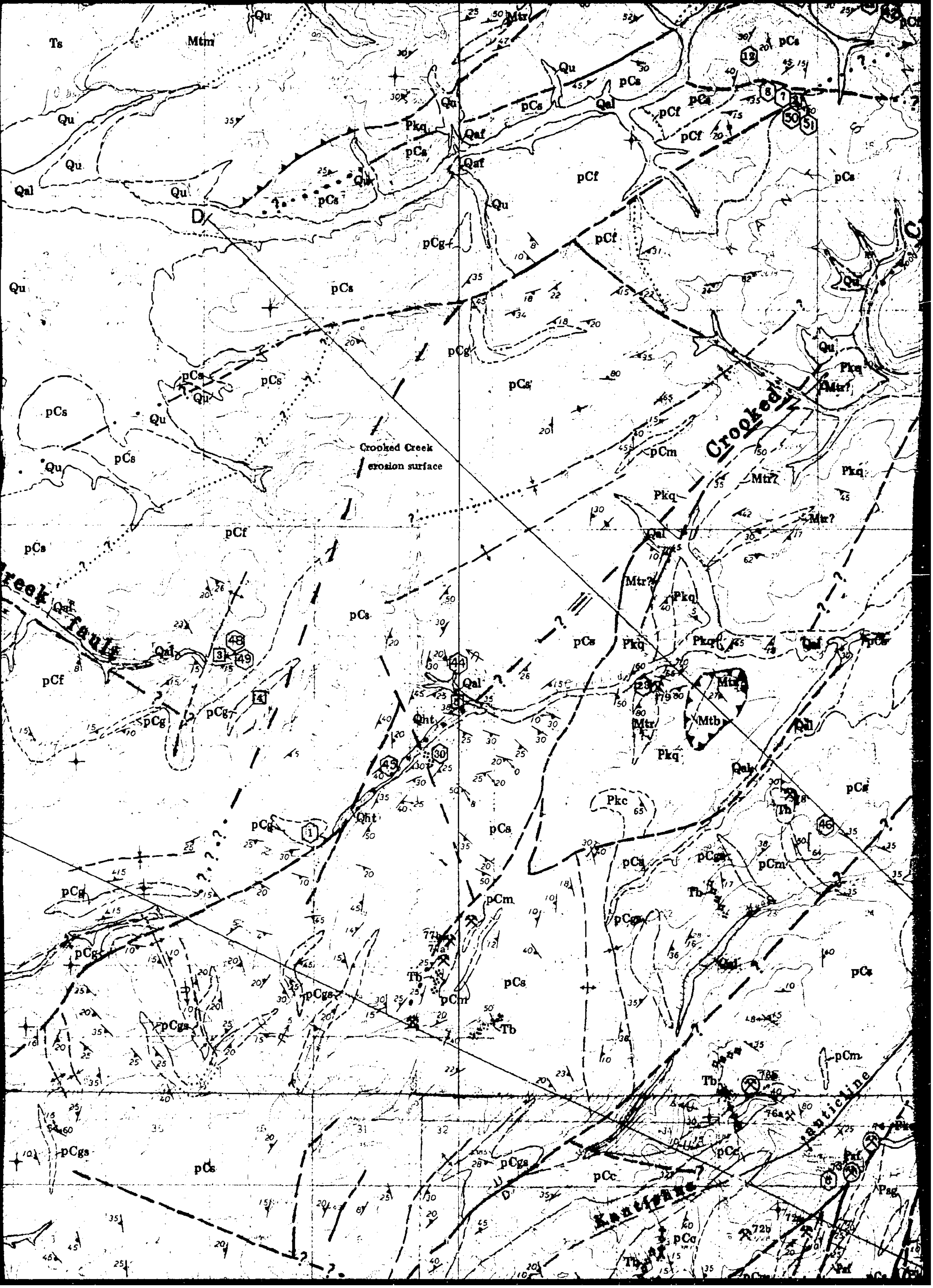
Contact

?

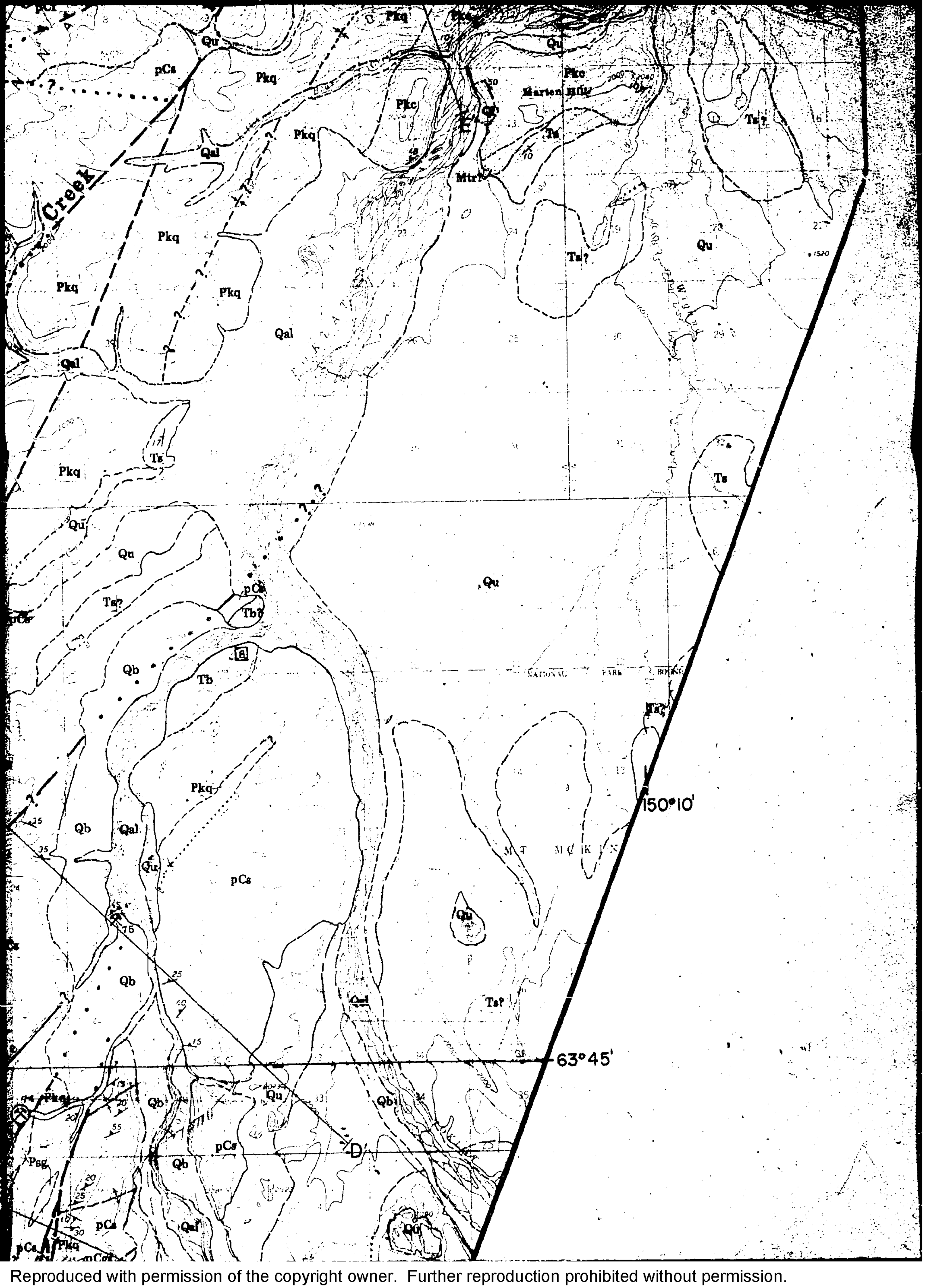
Thrust Fault; sawteeth on upper plate



tr
ry and Sericite Schist;
us, sericite rich, locally
phyritic textures,
and fine grained
ry resistant forming
kc
and Quartzite; light
with sheared clasts.
Contains minor slate
y, med-
caceous
y non-
orly ex-
Mtb
Mafic Metavolcanic Rocks and Chert; dark green-gray, aphanitic metabasalt and porphyritic meta-andesite. Includes minor but distinctive laminated, red cherts and gray phyllite. Fossiliferous limestone bed 3m thick denoted (f). Pillow structure denoted (p).
Ts
Qu
Qal
pCs
pCf
pCg
pCgs
Qaf
Sag ponds?
Otter Creek fault
fault
C
Shear zone
Active?
6



Crooked Creek
erosion surface
Crooked
Creek fault
anticline



Creek
Qu
pCs
Pkq
Pkc
Pkc
Marten Hill
Qb
Ts
Ts?
Mtr?
Qal
Ts?
Pkq
Qal
Ts
Qu
Ts?
pCs
Tb?
Qb
Tb
Qal
Qu
Qb
pCs
Qu
Ts?
Qb
Qb
Psg
Qu
63°45'
150°10'
NATIONAL PARK BOUNDARY
D'

D= downthrown side; arrows indicate movement

Outer Limit of Geologic Mapping

Anticline; showing trace and direction of crustal plane

Overturned Anticline; shows dip of limb and plunge

Syncline; showing trace o trough plane and axial p

31 inclined | vertical

Strike and Dip of Beds

vertical | horizontal | 67 inclined

Strike and Dip of Foliation

21 5c mica crenulation | 31 f 17 overturned isoclinal fold | 37 69 kink banding | 22 isoclinal fold right side up | 46 isoclinal fold upside down

Secondary Structural Features Showing Bearing and Plunge

vertical | 44 inclined

Strike and Dip of Cleavege

vertical | 32 inclined

Strike and Dip of Joints

Mineral Spring

E

Glacial Erratic

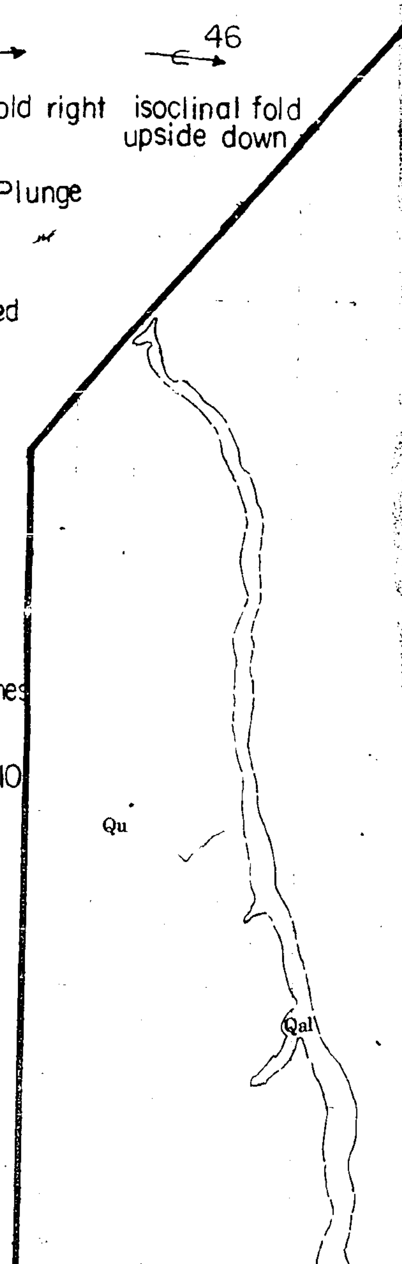
17

Location, Bulk Chemical Rock Analysis

Tables 1and 8

60 | 17

Mineral Prospects and Mines circle indicates production numbers keyed to tables 9,10



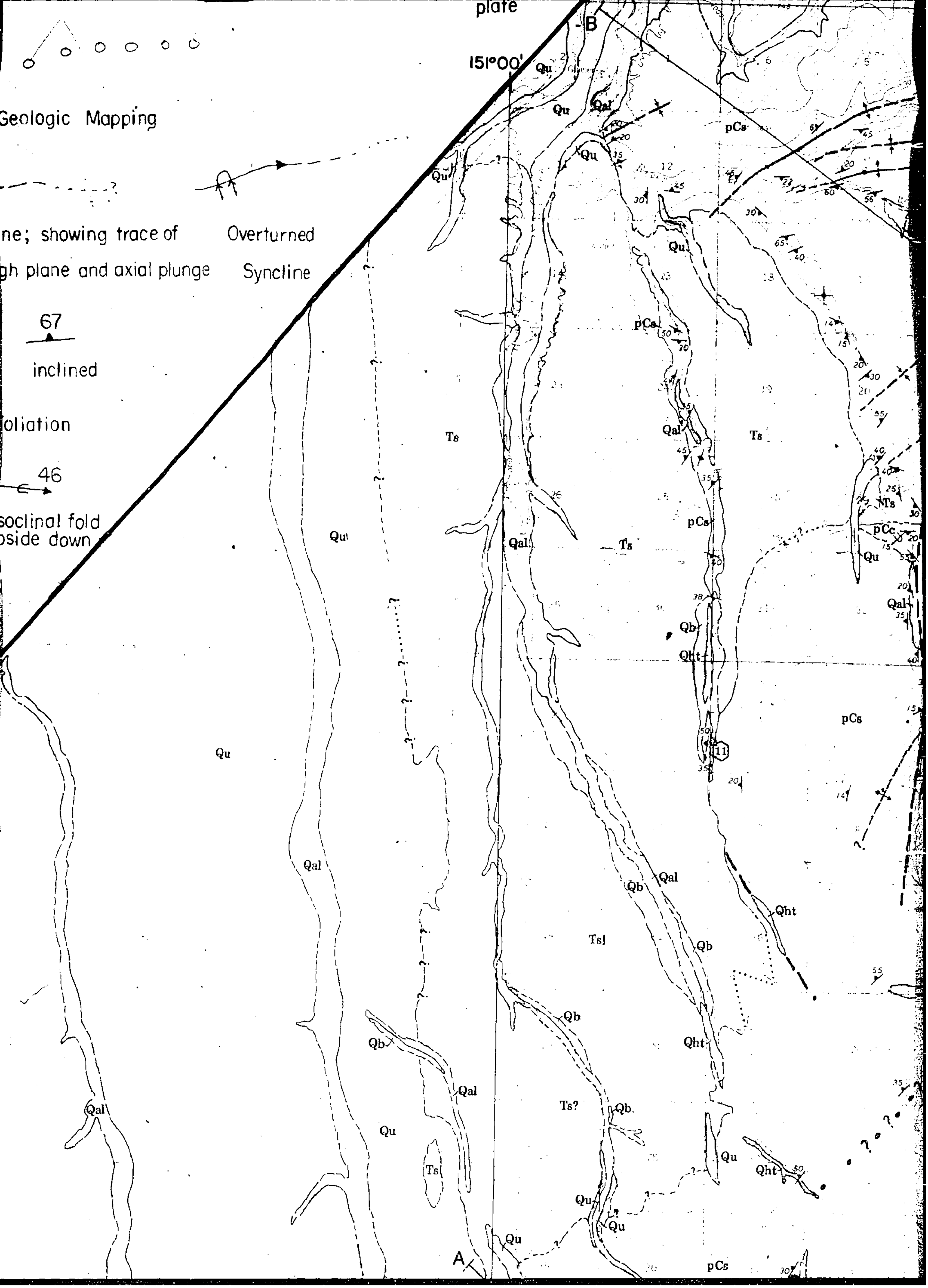
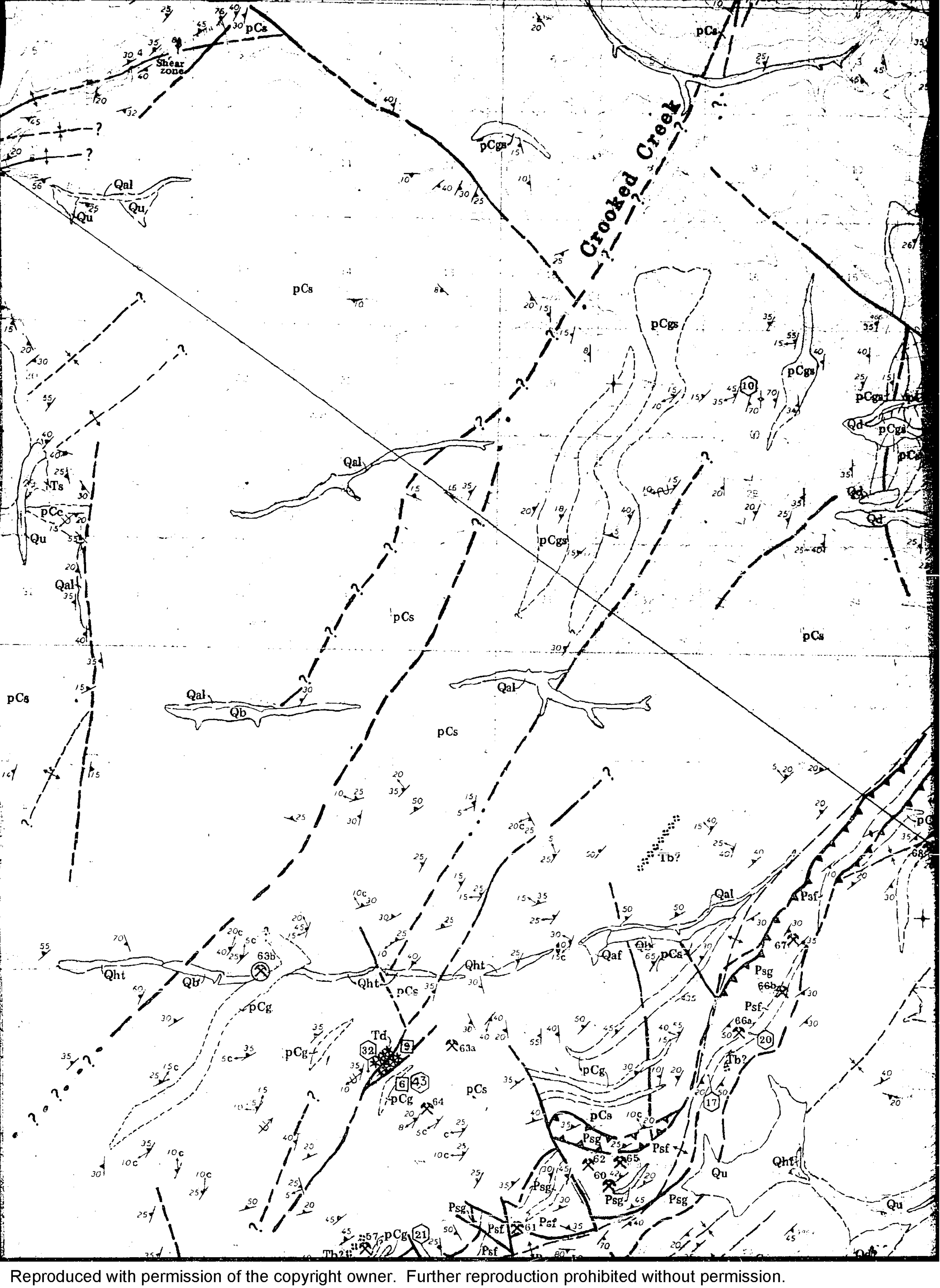
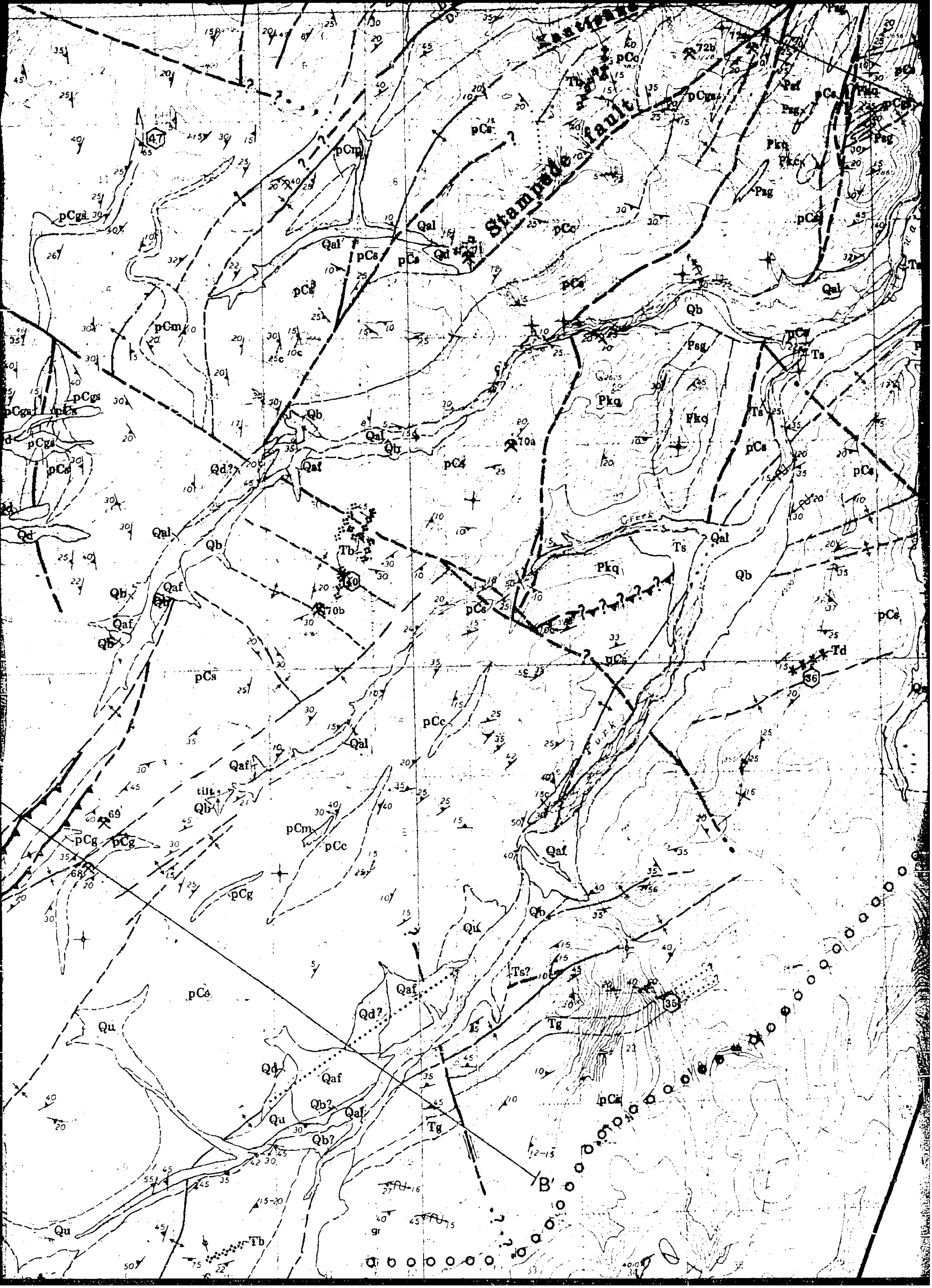
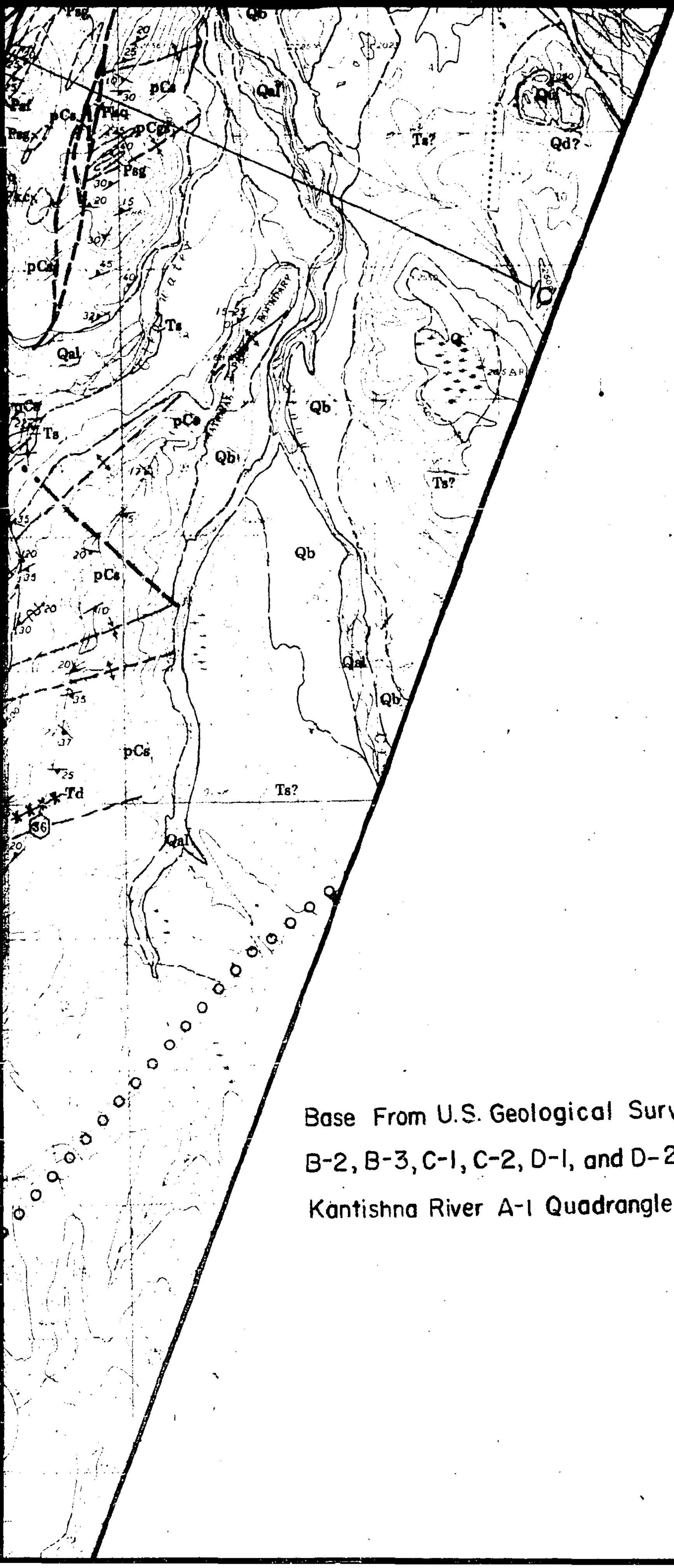


plate
B
151°00'
Geologic Mapping
ne; showing trace of
gh plane and axial plunge
Overturned
Syncline
67
inclined
oliation
46
soclinal fold
pside down
Qu
Qal
pCs
Ts
Qb
Qht
Tsl
Ts?
A



Crooked Creek
Shear zone
pCs
pCgs
pCg
pCc
Qal
Qu
Qb
Qht
Qaf
Qd
Ts
Td
Tb?
Psg
Psf
63a
63b
64
66a
66b
67
60
61
62
65
57

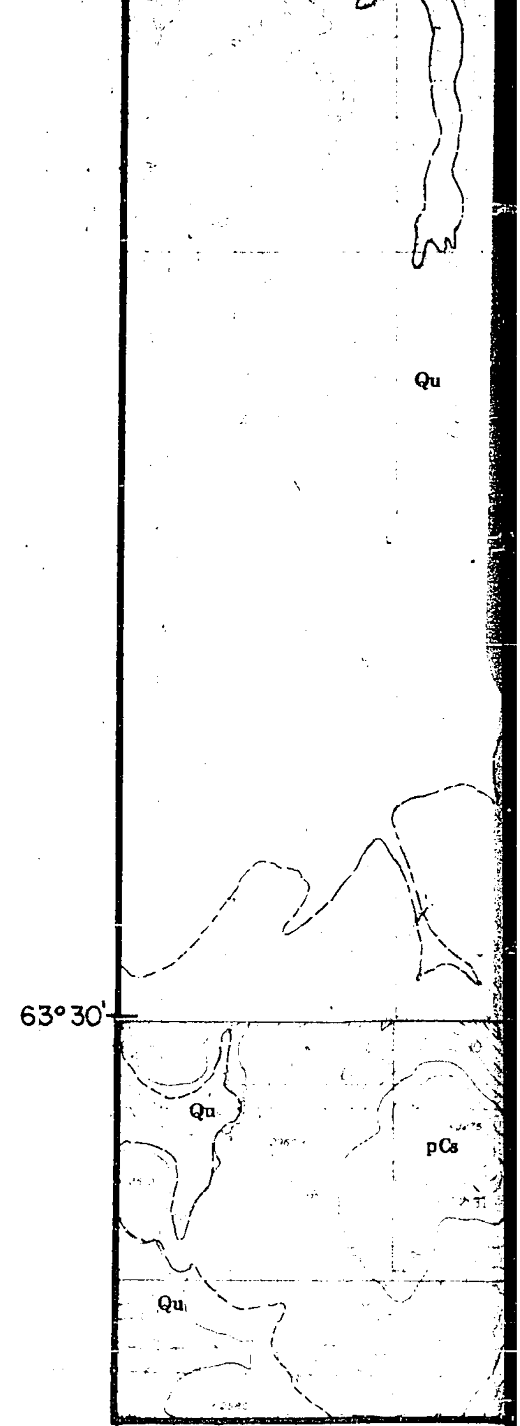

Stampede fault
pCs
pCc
pCm
pCgs
pCg
Qal
Qaf
Qb
Qd
Qu
Pkq
Psg
Ts
Tb
Tg
Td
Creek
Fork
B'

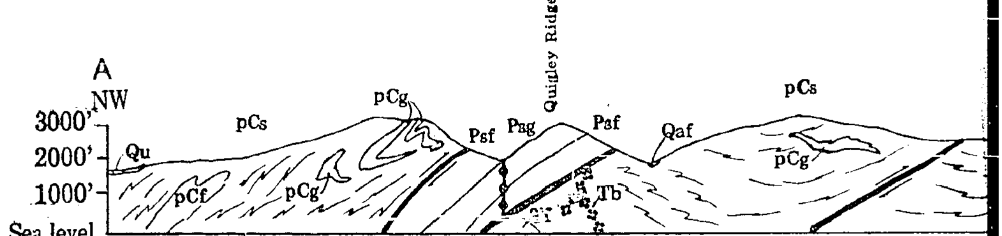


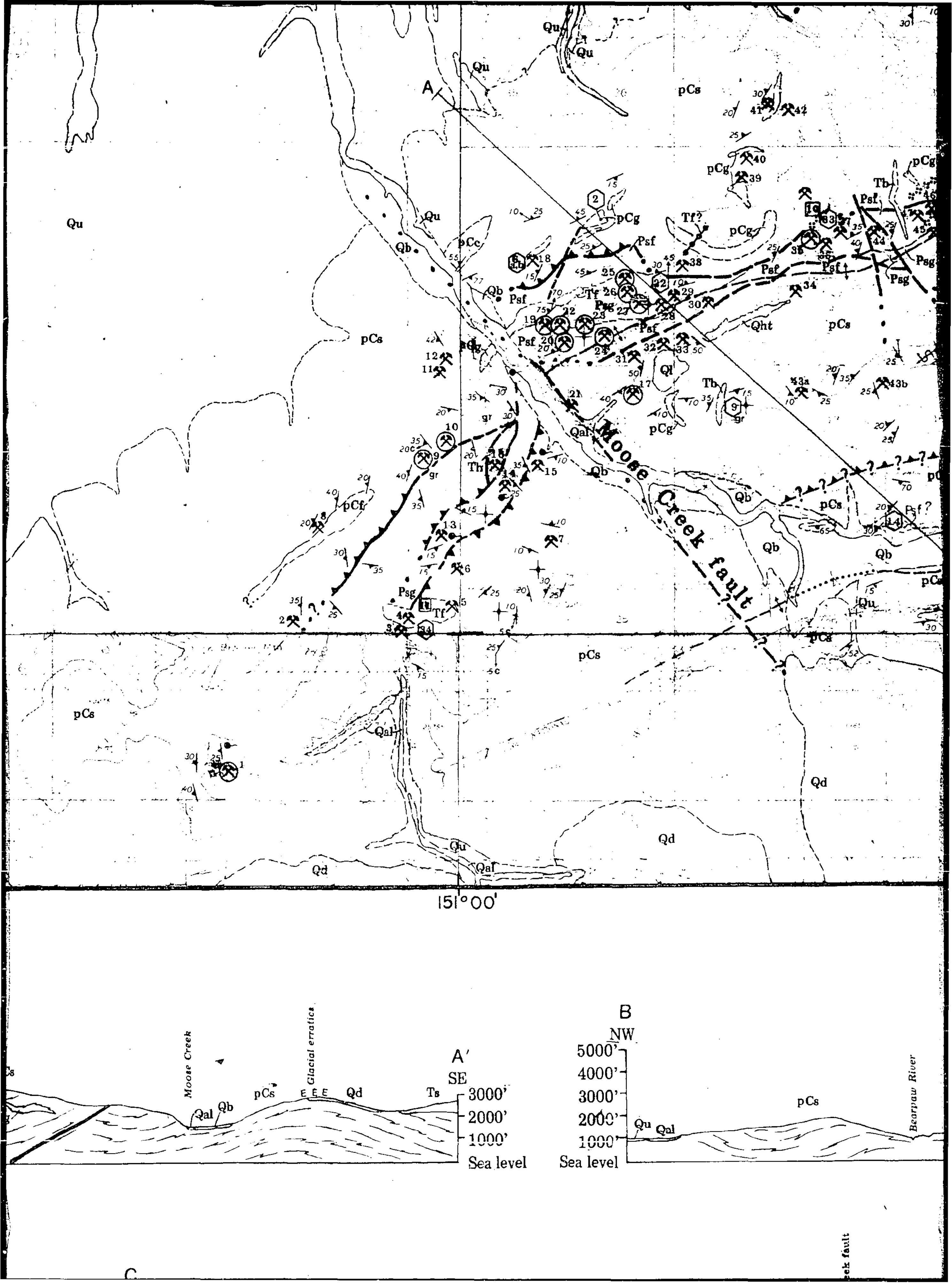
Base From U.S. Geological Survey Mt. McKinley B-1, B-2, B-3, C-1, C-2, D-1, and D-2 Quadrangles and Kantishna River A-1 Quadrangle (1954), Alaska

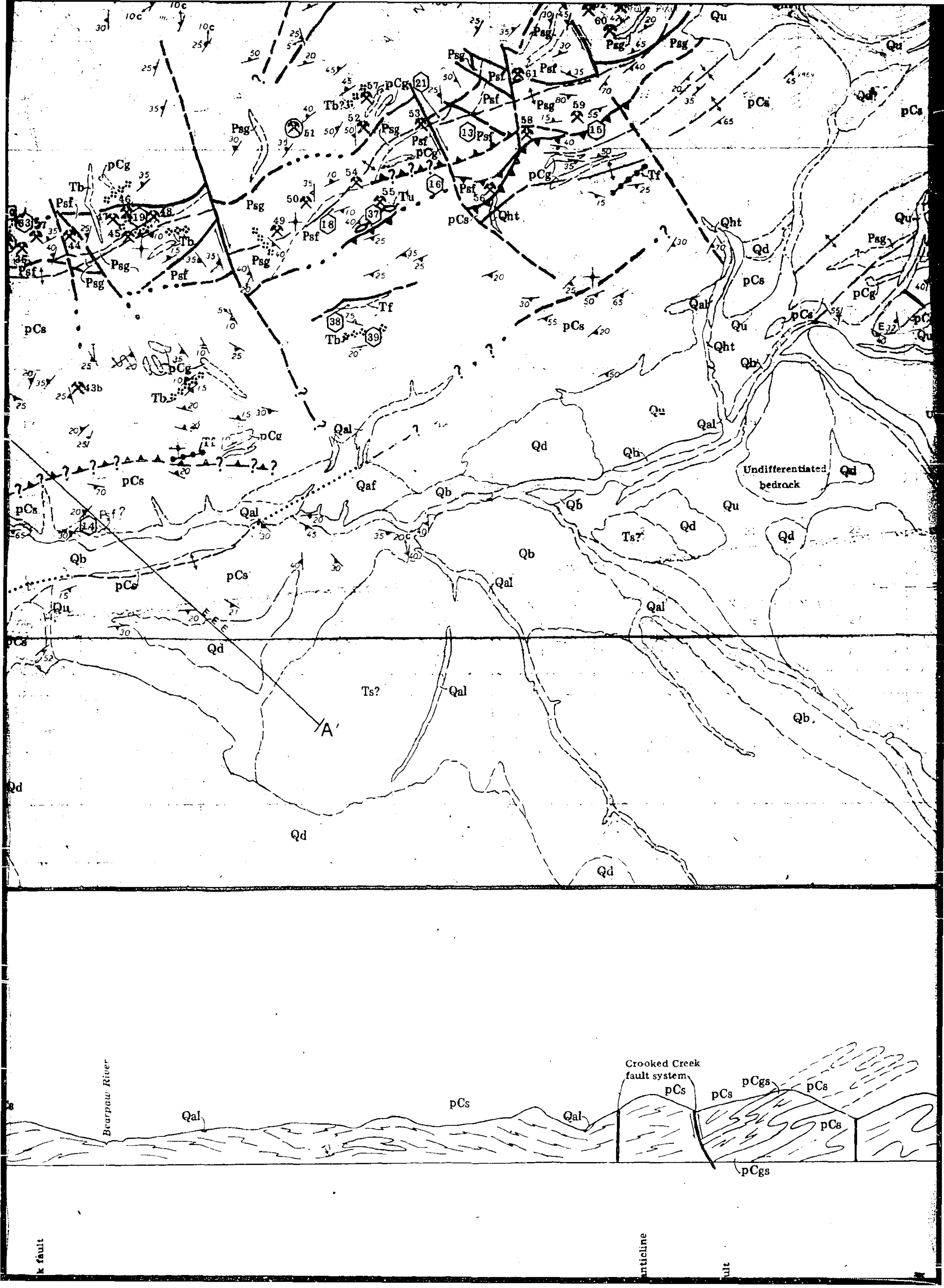
North

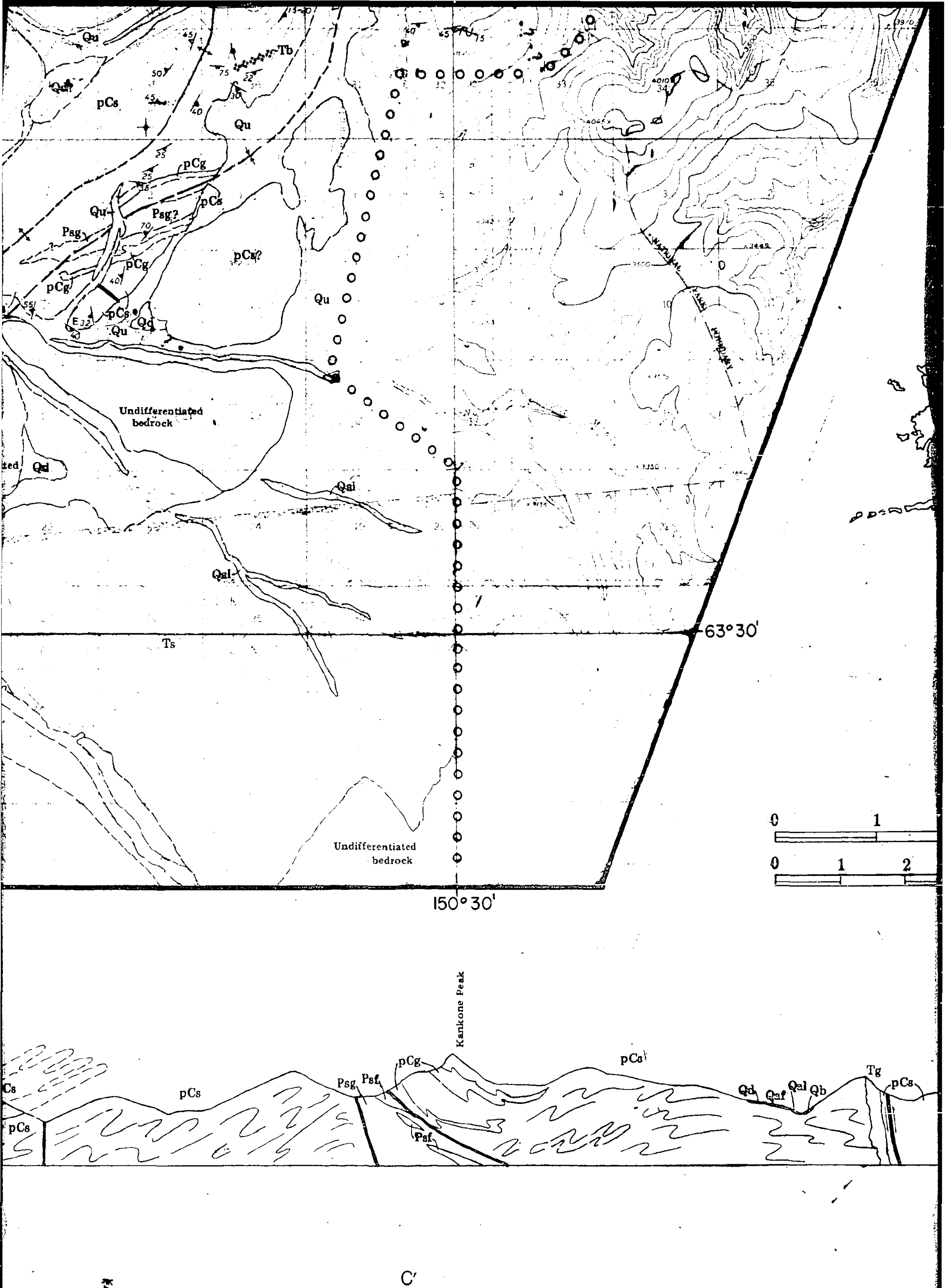
(1954)

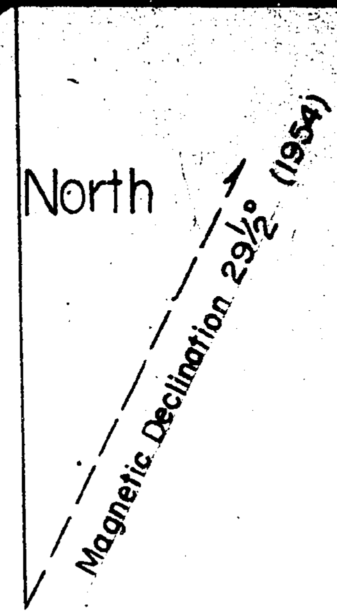

Qu
63°30'
Qu
pCs
Qu


A
NW
3000'
2000'
1000'
Sea level
Qu
pCs
pCg
pCf
pCg
Psf
Psg
Quigley Ridge
Psf
Qaf
Tb
pCs
pCg


Moose Creek fault
151°00'
A
A'
SE
B
NW
Qu
Qb
Qal
Qd
pCs
pCg
Psf
Psg
Tf
Tb
Qht
Ql
Th
pCf
pCc
Ts
gr
Moose Creek
Glacial erratics
Bearpaw River
5000'
4000'
3000'
2000'
1000'
Sea level
C

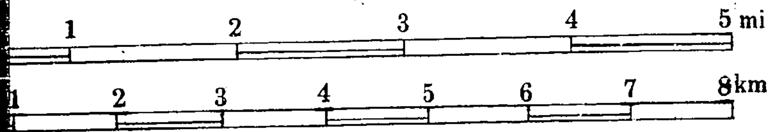

Qu
pCs
Psg
Psf
pCg
Tb
Tf
Tu
Qht
Qd
Qal
Qb
Qaf
Ts?
Undifferentiated bedrock
A'
Crooked Creek fault system
Bearpaw River
pCgs
anticline

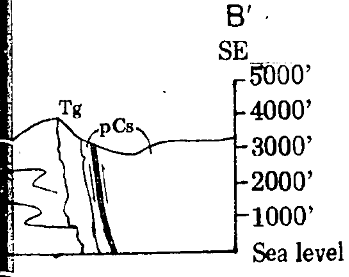

Qu
pCs
Qu
Tb
pCg
Psg?
pCs
Qu
Psg
pCs?
pCg
pCg
pCs
Qd
Qu
Qu
Undifferentiated
bedrock
Qd
Qal
Qal
Ts
63°30'
Undifferentiated
bedrock
0
1
0
1
2
150°30'
Kankone Peak
pCs
pCg
Psg
Psf
pCs
Cs
pCs
Psf
Qd
Qaf
Qal
Qb
Tg
pCs
C'

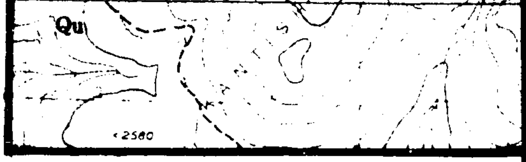


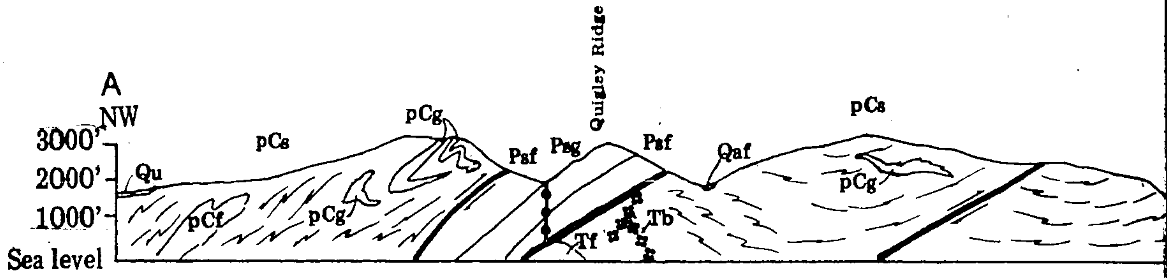
Location map

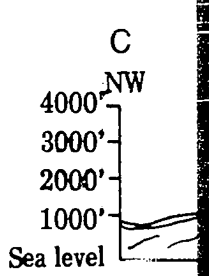
Scale 1:63,360

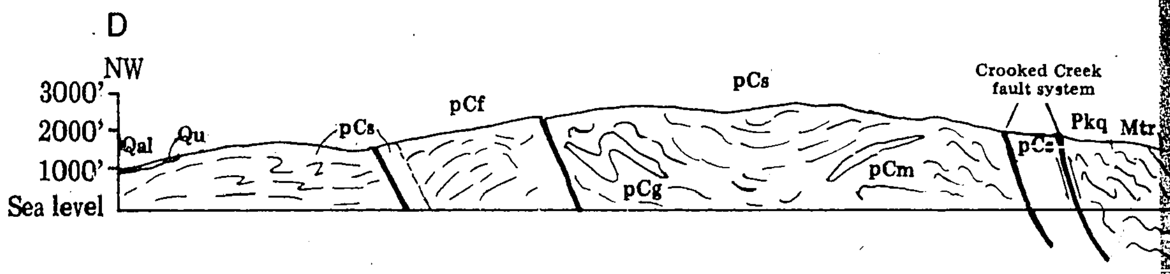




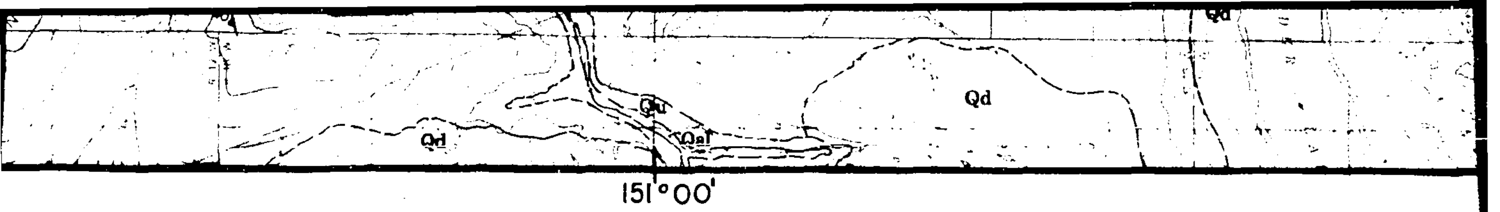

Qu
2580

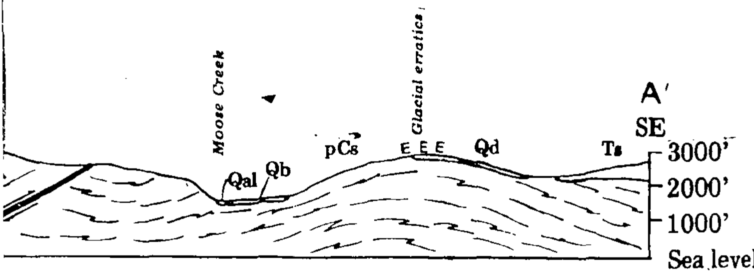

A
NW
3000'
2000'
1000'
Sea level
Qu
pCs
pCg
pCf
Psf
Psg
Quigley Ridge
Psf
Qaf
pCs
pCg
Tb
Tf

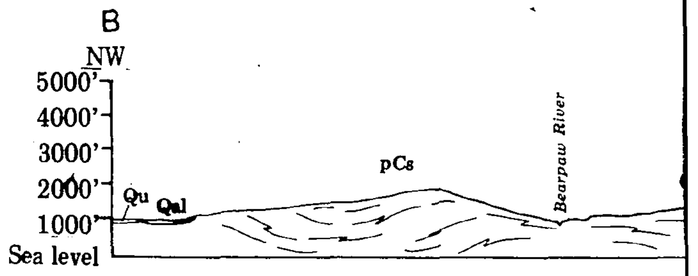

C
NW
4000'
3000'
2000'
1000'
Sea level

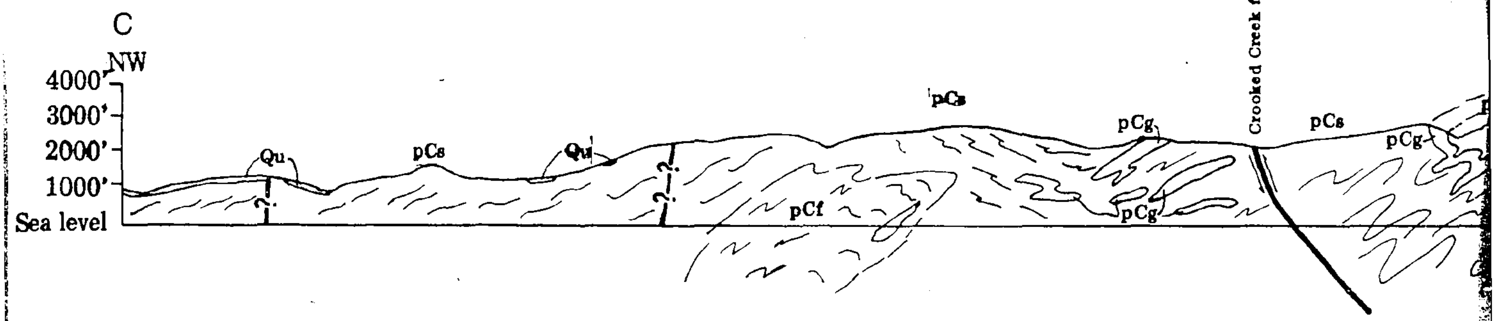

D
NW
3000'
2000'
1000'
Sea level
Qal
Qu
pCs
pCf
pCs
pCg
pCm
Crooked Creek
fault system
pCs
Pkq
Mtr

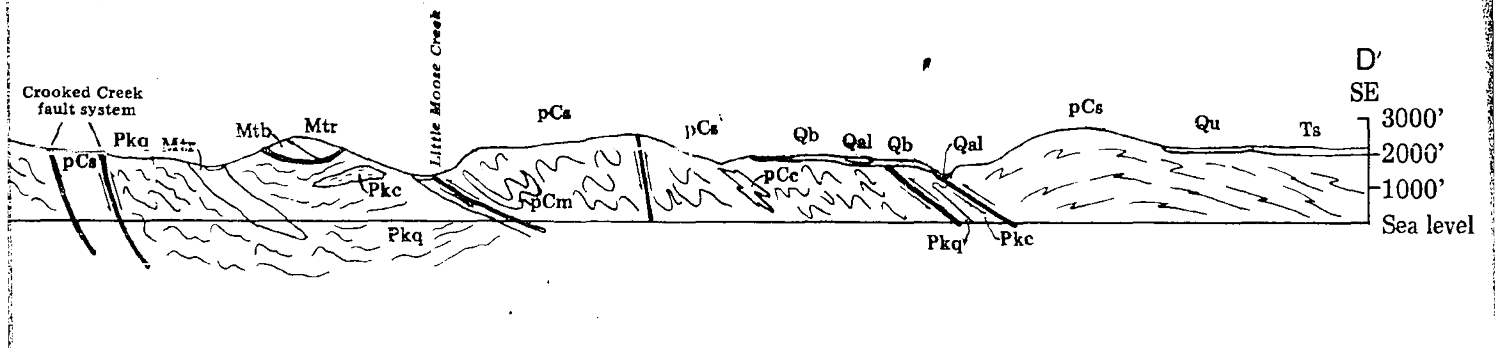
GEOLOGIC



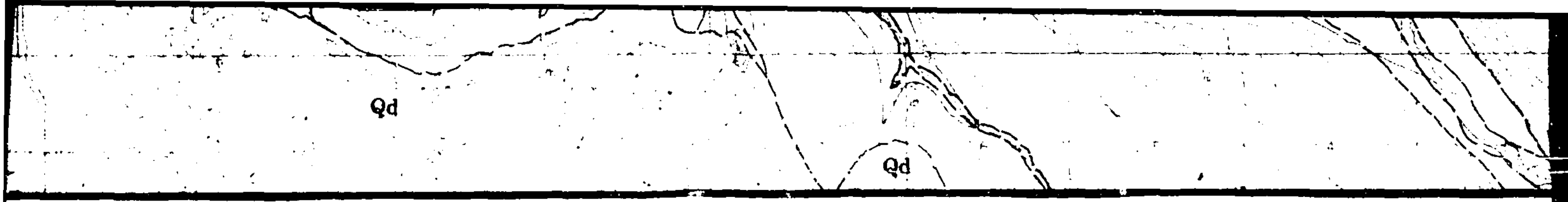


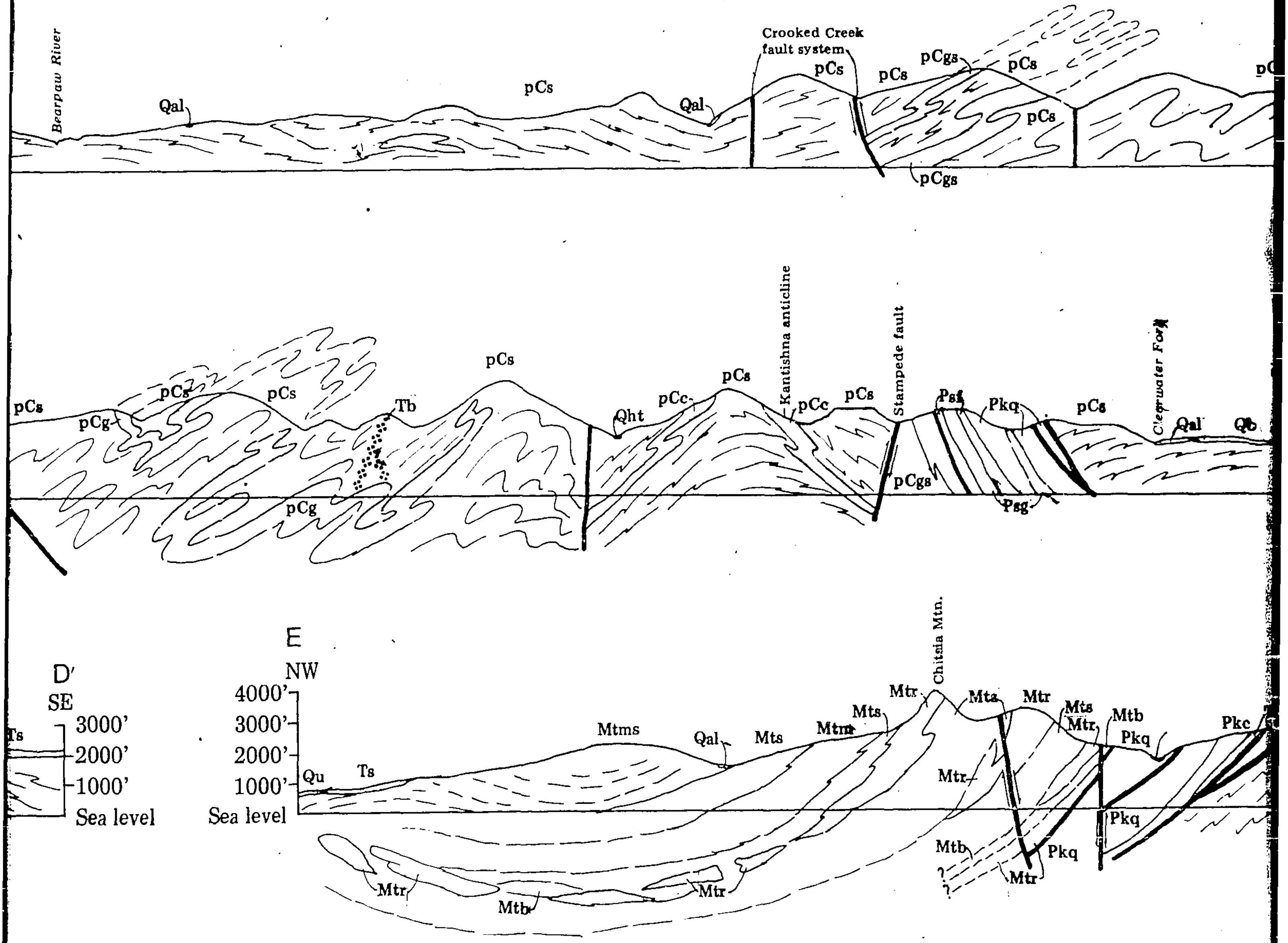






GIC MAP AND STRUCTURE SECT

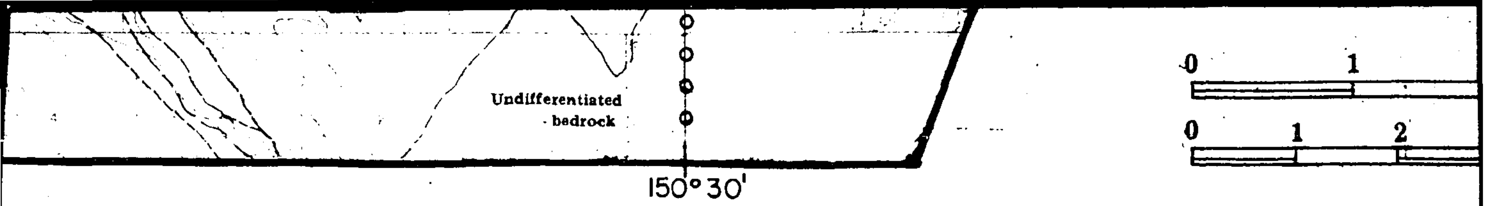


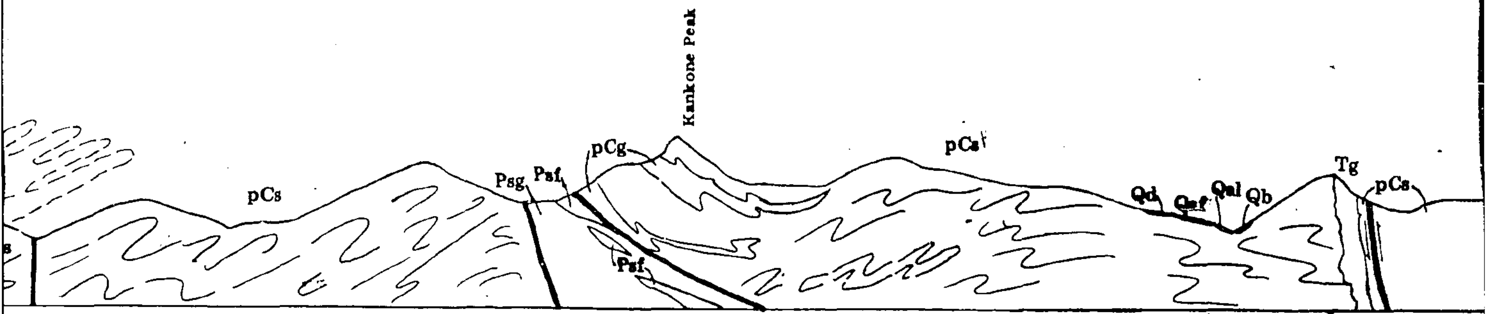


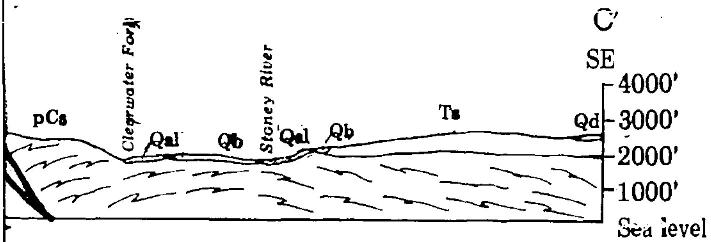
ECTIONS OF THE KANTISHNA HI

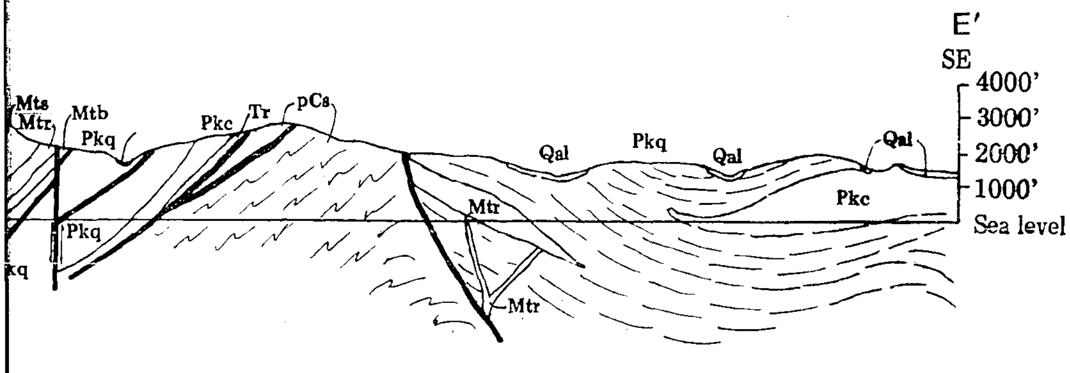
by T. K. Bundtzen

1981







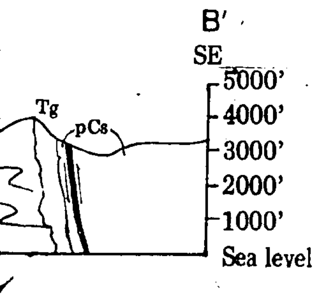


NA HILLS, MOUNT MC KINLEY QU

Scale 1:63,360

1 2 3 4 5 mi

1 2 3 4 5 6 7 8 km



Y QUADRANGLE ALASKA

Plate 2

Metamorphic Facies Map of the Kantis

Birch Creek Schist Prograde Upper Greenschist to Lower(?) A
Retrograde Greenschist Metamorphic Facies. For Mineral Ass

Spruce Creek Sequence Biotite Zone, Greenschist Metamorph
Events, if Both Exist, are Indistinguishable. For Mineral Assemb

Keevy Peak Formation and Totatlanika Schist Chlorite Zone, G
Facies. For Mineral Assembledges, See Tables 5 and 6 in Te

Garnet Comp. Alm68
Pyr 17 UCE=11.603

Sample Site of Analyzed Garnet Showing Estimated M
Percent End Members and Unit Cell Edge in Angstro
to Table 3 in Text.

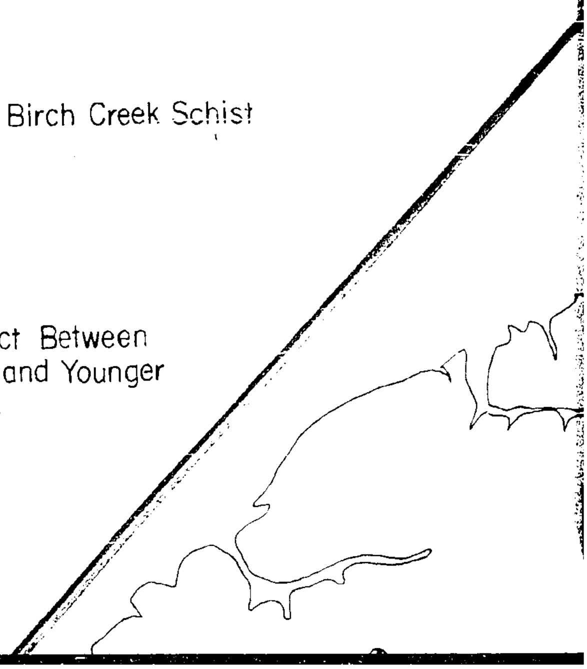
Thin Section Location

Index Mineral Control Based on Megascopic Hand Specimen Examination

Mineral Isograd in Birch Creek Schist

Major Fault

Approximate Contact Between Crystalline Terrane and Younger Bedded Sequences



Department of

ɫhe Kantishna Hills, Alaska

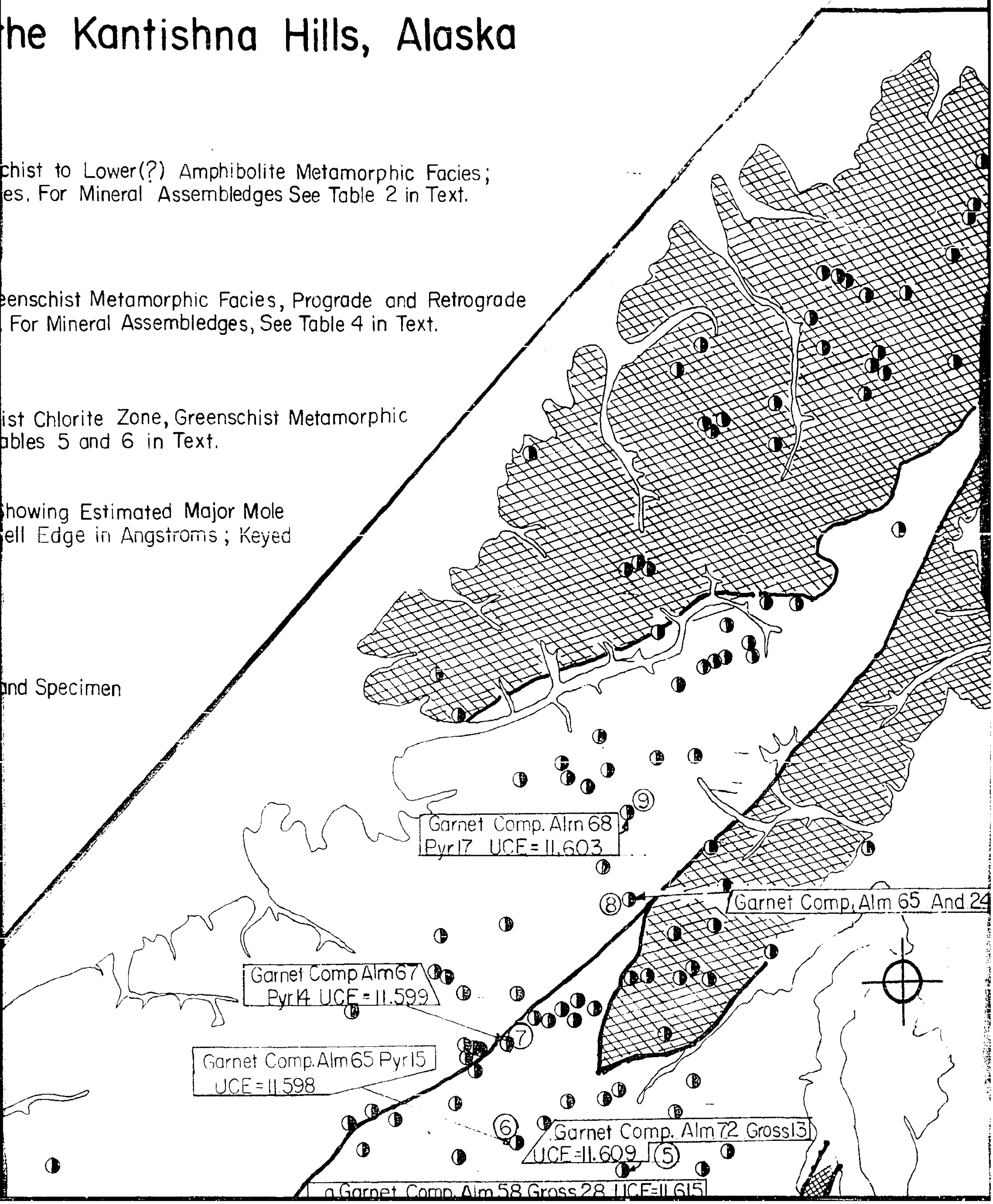
chist to Lower(?) Amphibolite Metamorphic Facies;
es. For Mineral Assembledges See Table 2 in Text.

eenschist Metamorphic Facies, Prograde and Retrograde
For Mineral Assembledges, See Table 4 in Text.

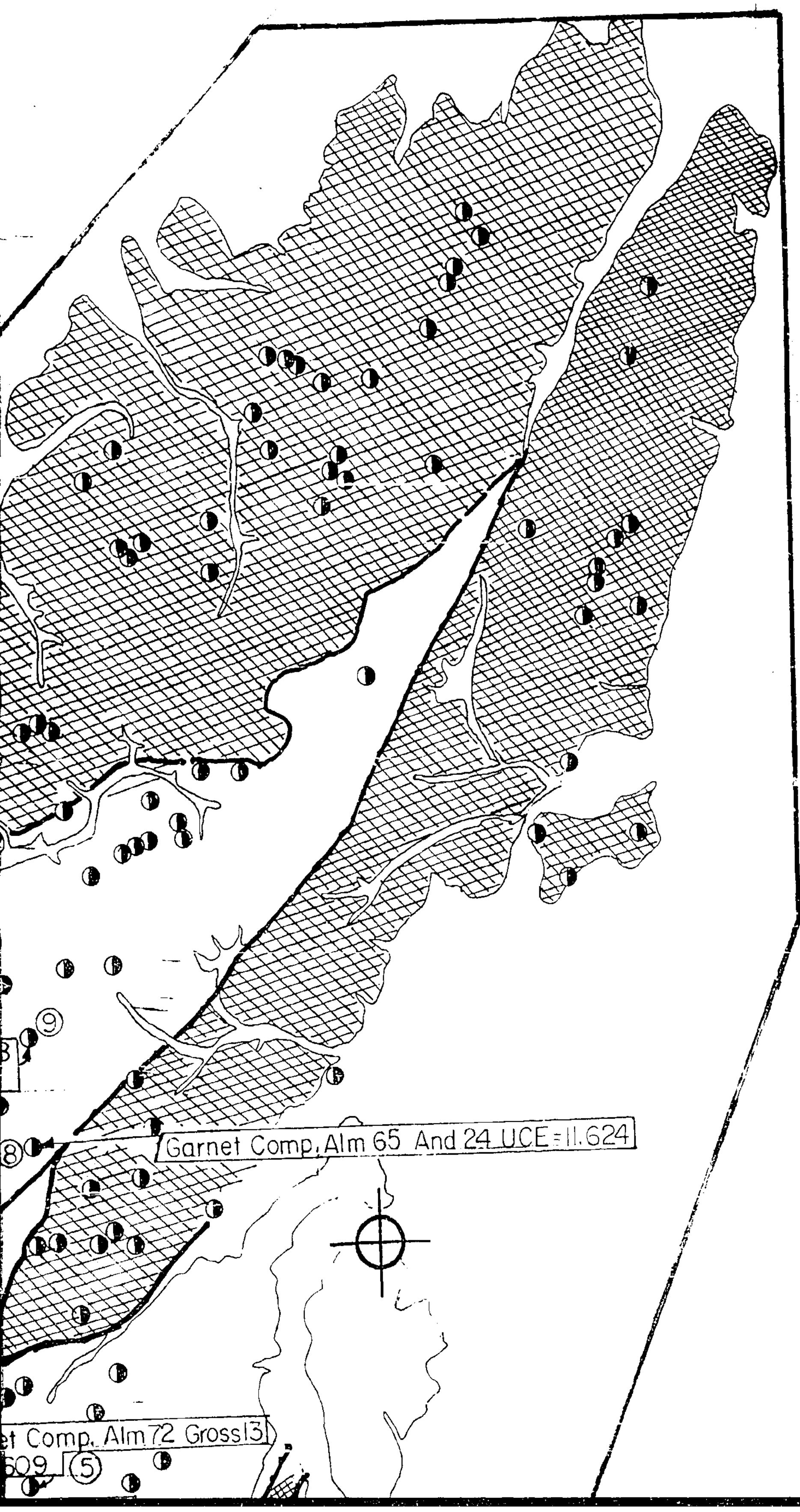
ist Chlorite Zone, Greenschist Metamorphic
ables 5 and 6 in Text.

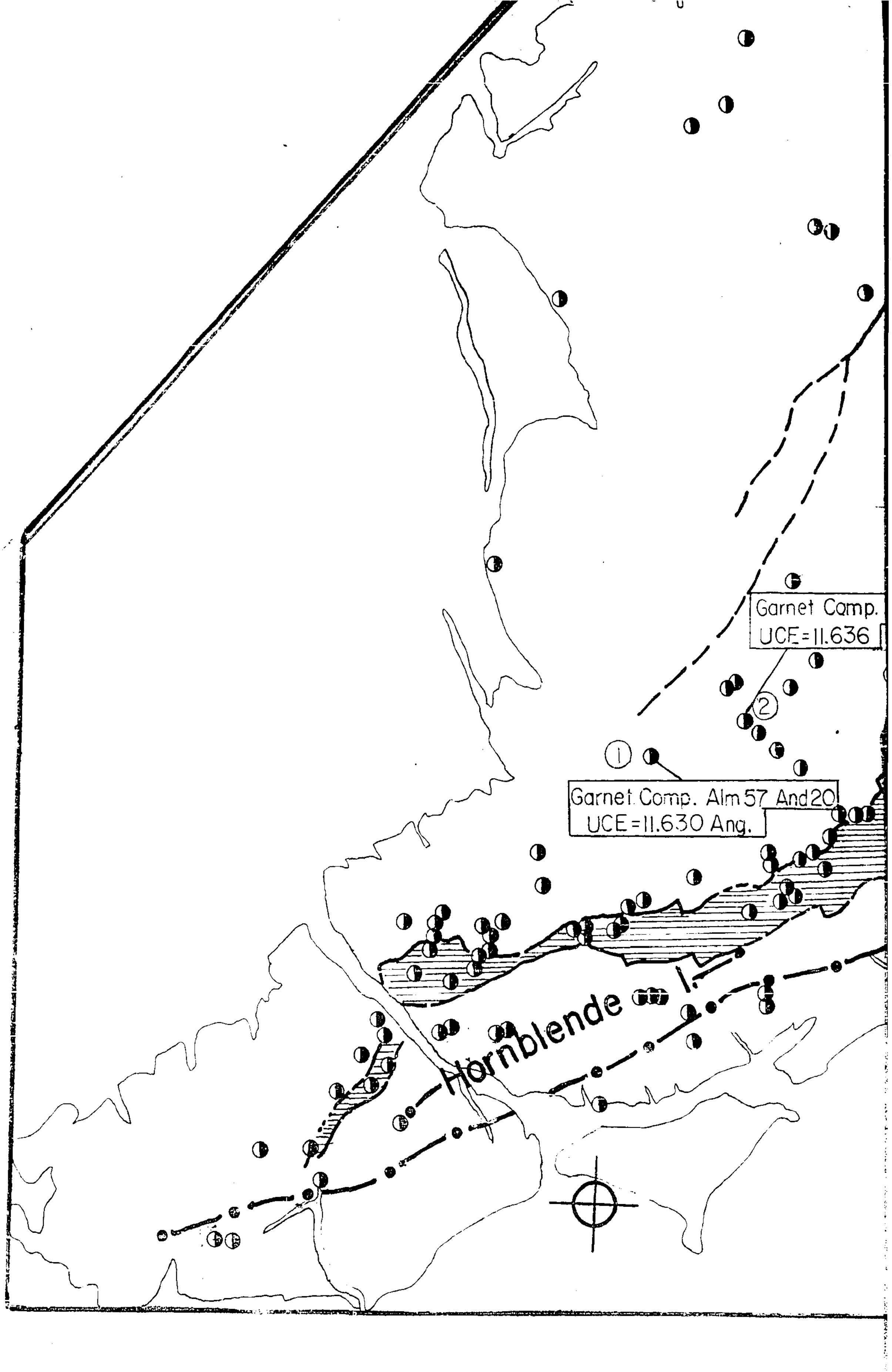
howing Estimated Major Mole
ell Edge in Angstroms; Keyed

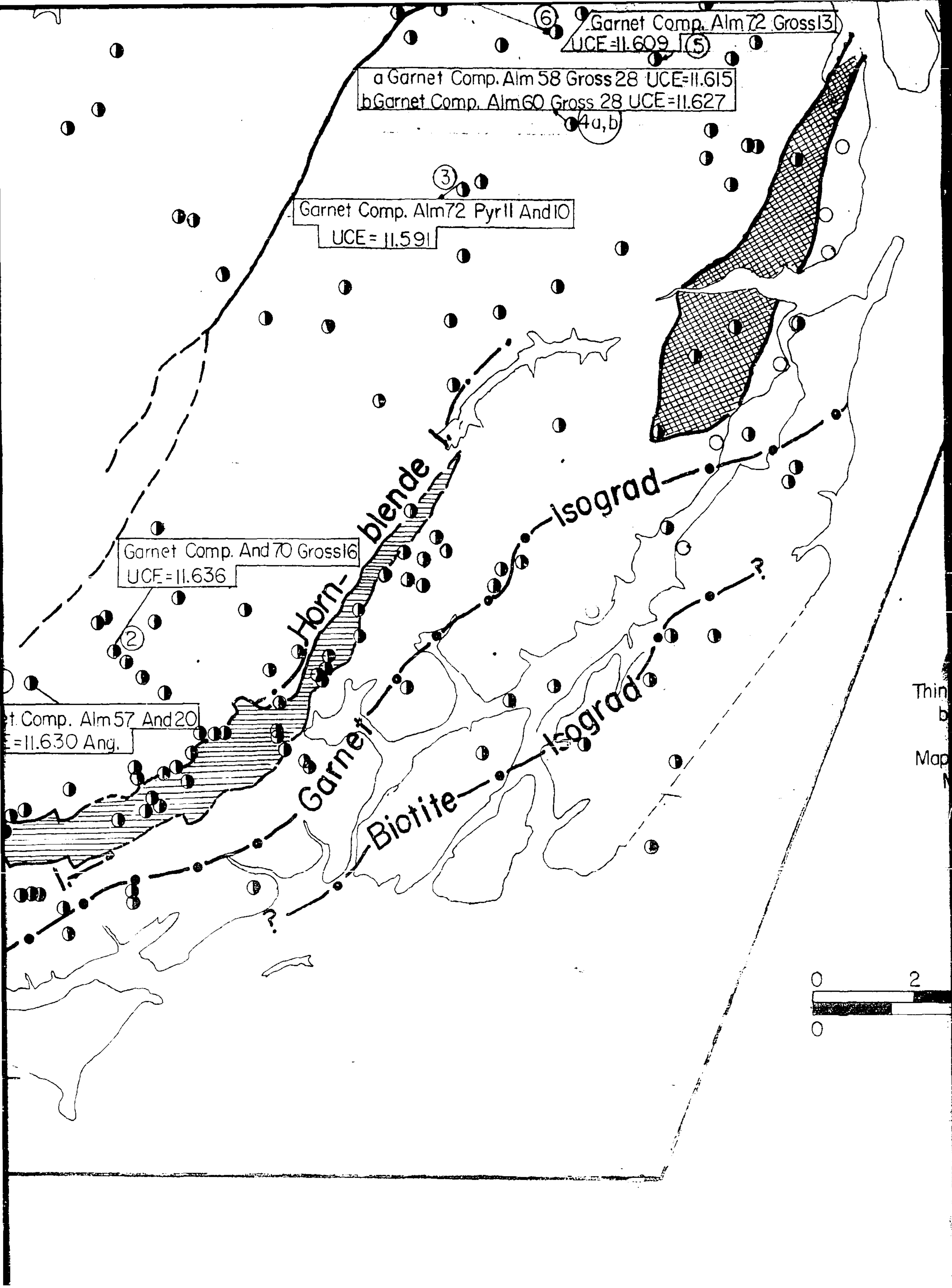
ınd Specimen



Department of Geology, University of Alaska




Garnet Comp.
UCE=11.636
2
1
Garnet Comp. Alm 57 And20
UCE=11.630 Ang.
Hornblende
I.



Garnet Comp. Alm72 Gross13
UCE=11.609
a Garnet Comp. Alm 58 Gross 28 UCE=11.615
b Garnet Comp. Alm60 Gross 28 UCE=11.627
4a,b
3
Garnet Comp. Alm72 Pyr11 And10
UCE= 11.591
Garnet Comp. And70 Gross16
UCE=11.636
2
et Comp. Alm57 And20
E=11.630 Ang.
Hornblende
Isograd
Garnet
Biotite
Isograd
?
?
0
2
0
Thin
b
Map
N

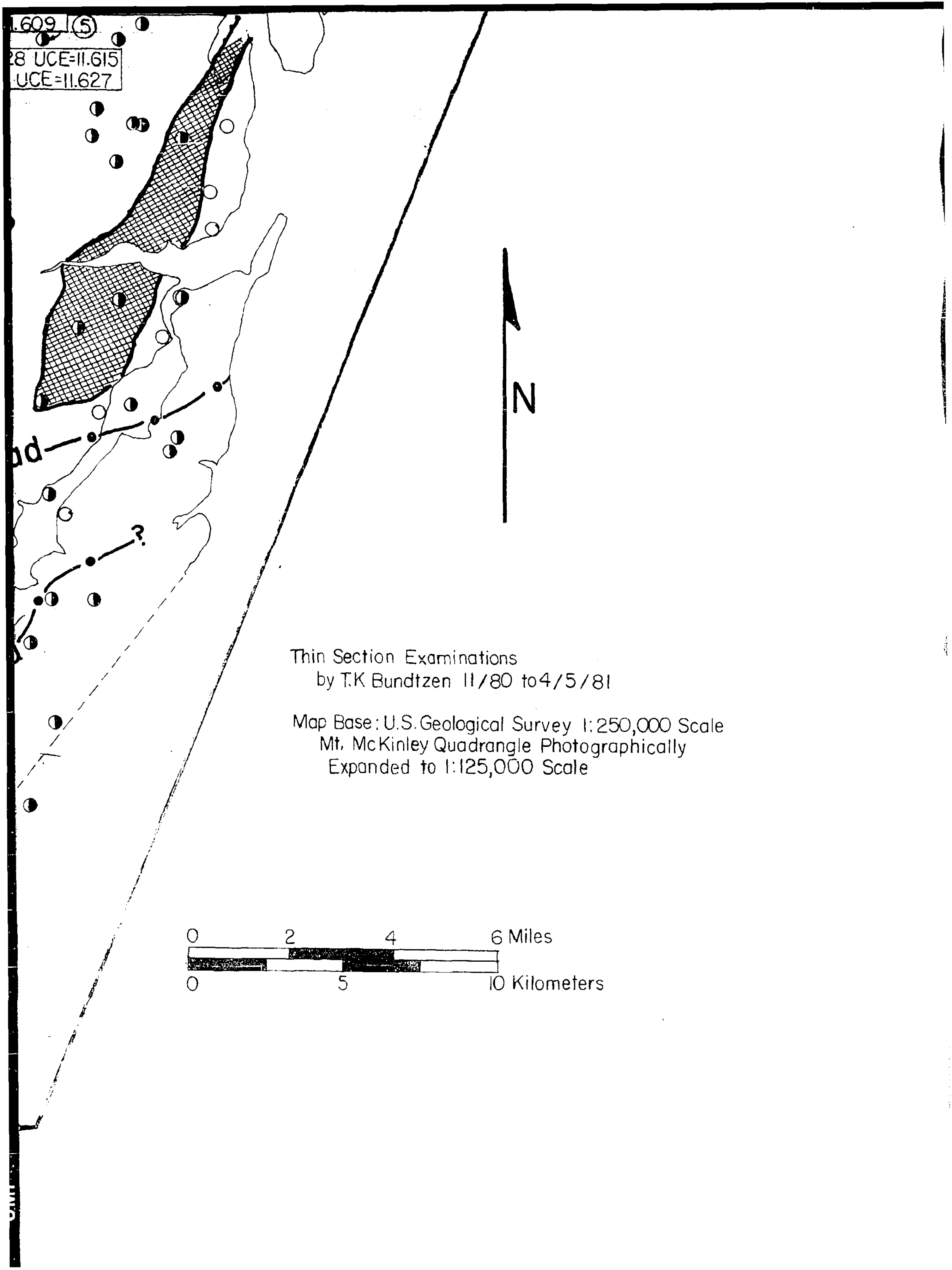
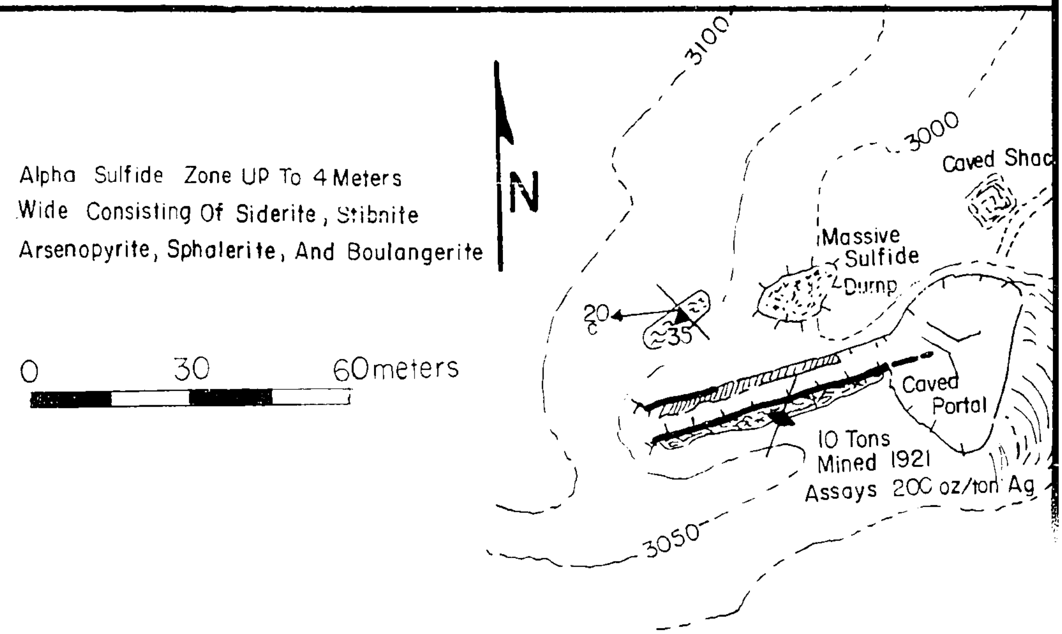
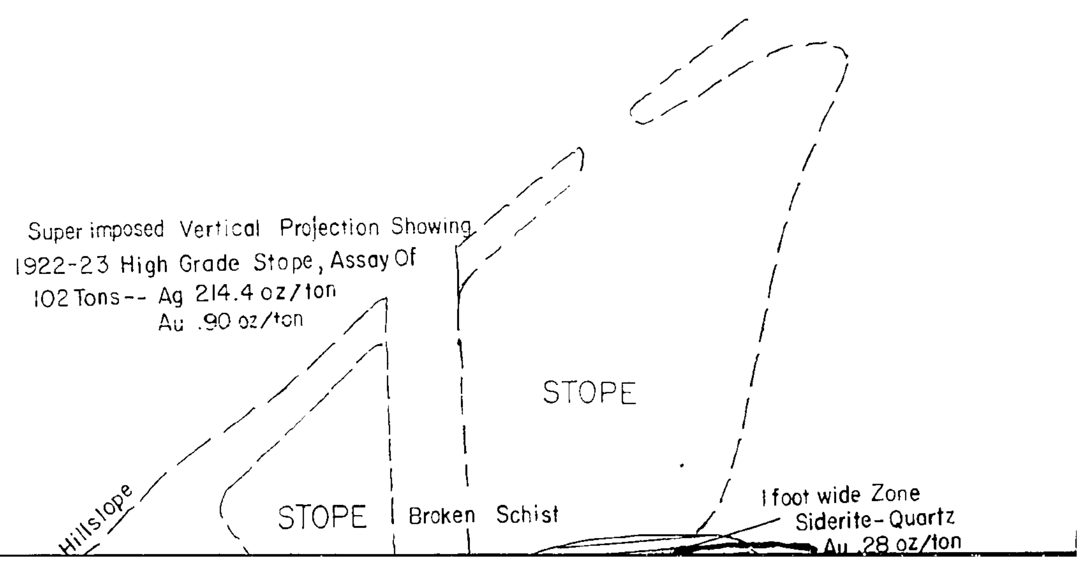
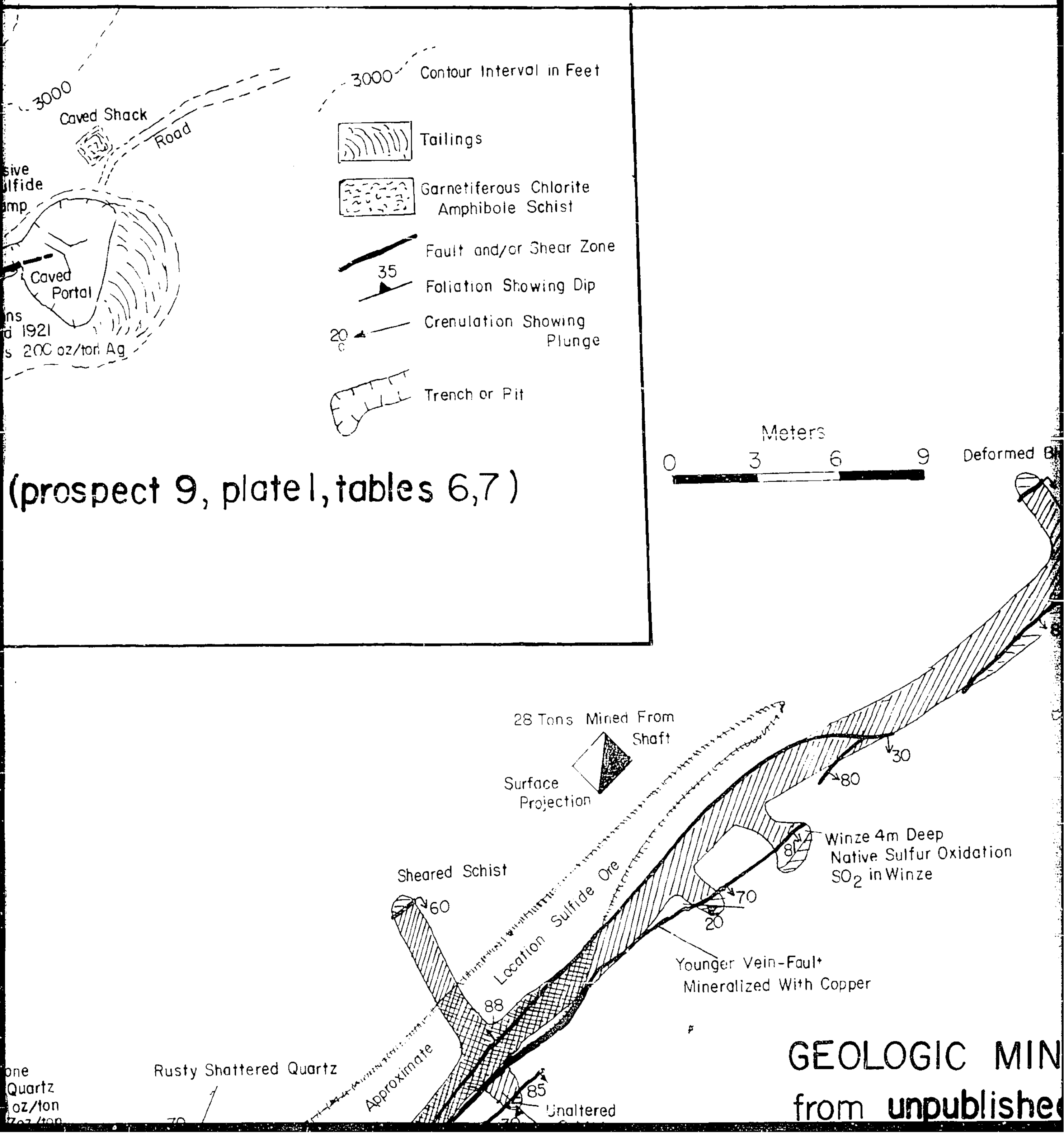

UCE=11.615
UCE=11.627
N
Thin Section Examinations
by T.K Bundtzen 11/80 to 4/5/81
Map Base: U.S. Geological Survey 1:250,000 Scale
Mt. McKinley Quadrangle Photographically
Expanded to 1:125,000 Scale
0 2 4 6 Miles
0 5 10 Kilometers

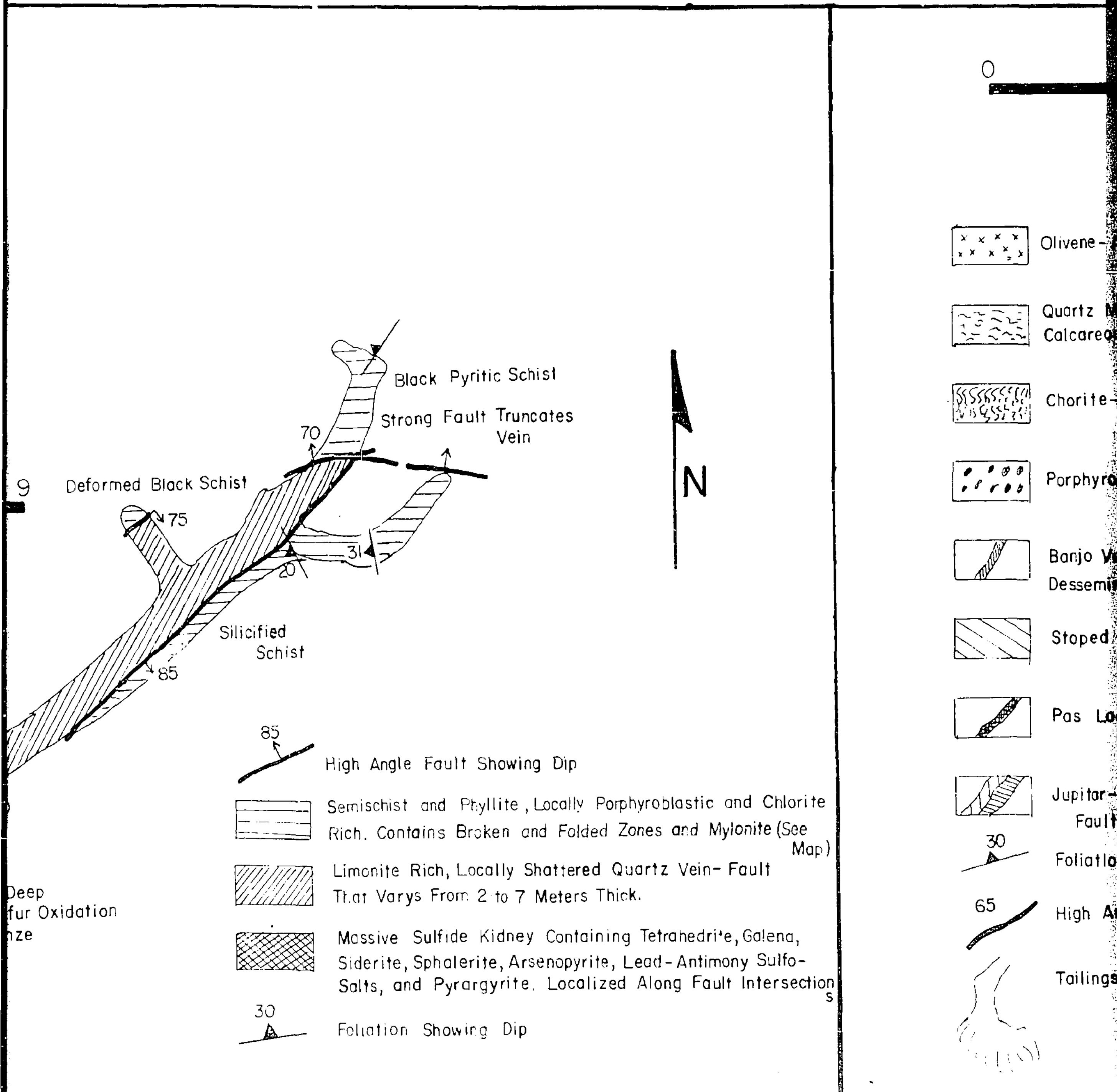
PLATE 3



SKETCH OF ALPHA MINE, (prospec




3000
Caved Shack
Road
sive
lfide
mp
Caved
Portal
ns
d 1921
s 200 oz/ton Ag
3000 Contour Interval in Feet
Tailings
Garnetiferous Chlorite
Amphibole Schist
Fault and/or Shear Zone
35
Foliation Showing Dip
20
Crenulation Showing
Plunge
Trench or Pit
(prospect 9, plate I, tables 6,7)
Meters
0 3 6 9
Deformed
28 Tons Mined From
Shaft
Surface
Projection
30
80
Winze 4m Deep
Native Sulfur Oxidation
SO_2 in Winze
Sheared Schist
60
Location Sulfide Ore
70
20
Younger Vein-Fault
Mineralized With Copper
88
Approximate
one
Quartz
oz/ton
Rusty Shattered Quartz
85
Unaltered
GEOLOGIC MIN
from unpublishe



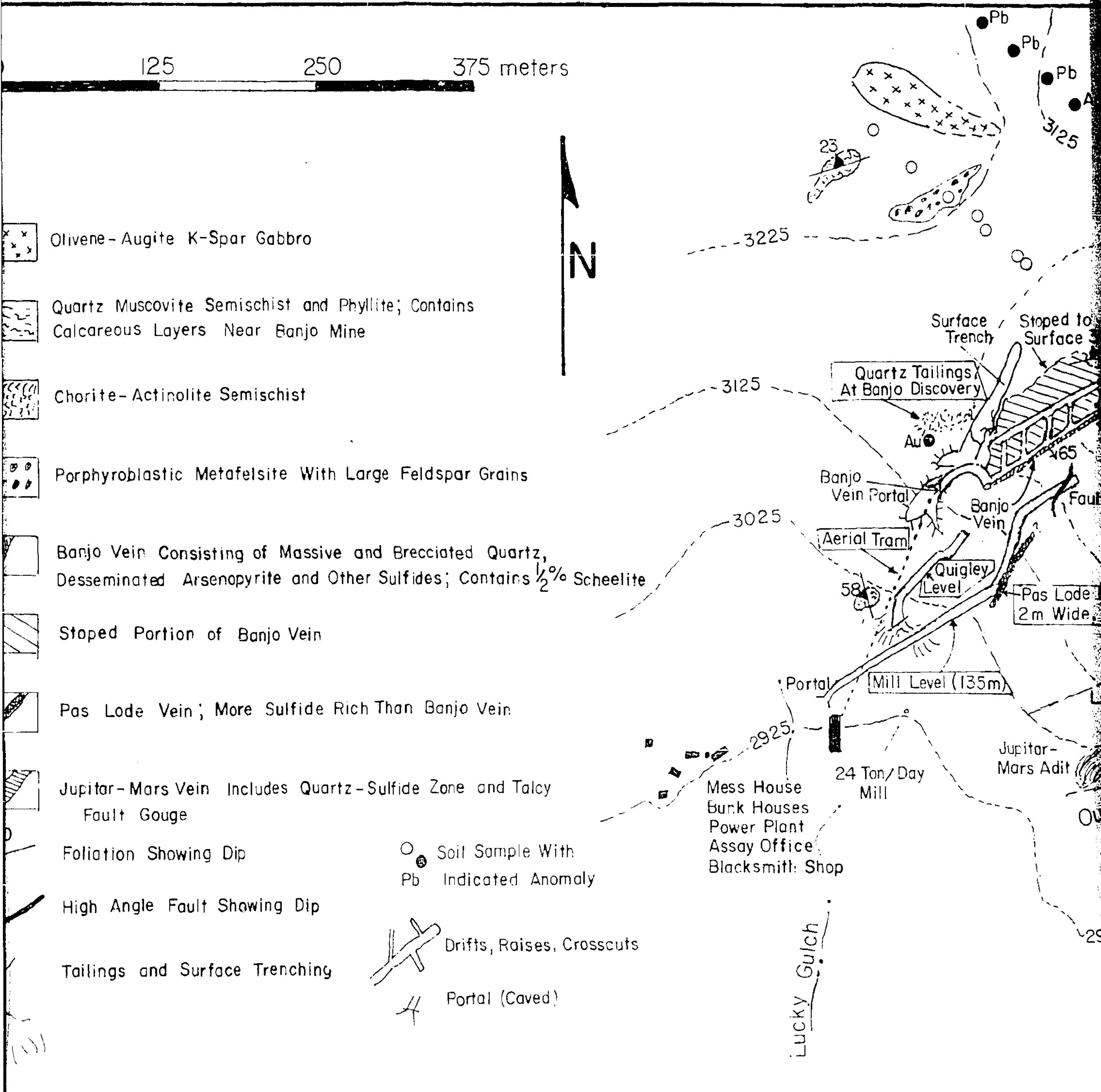
GIC MINE MAP OF THE RED TOP MINE

npublished map by Alaska Treadwell Gold

GEOLO

OF JU

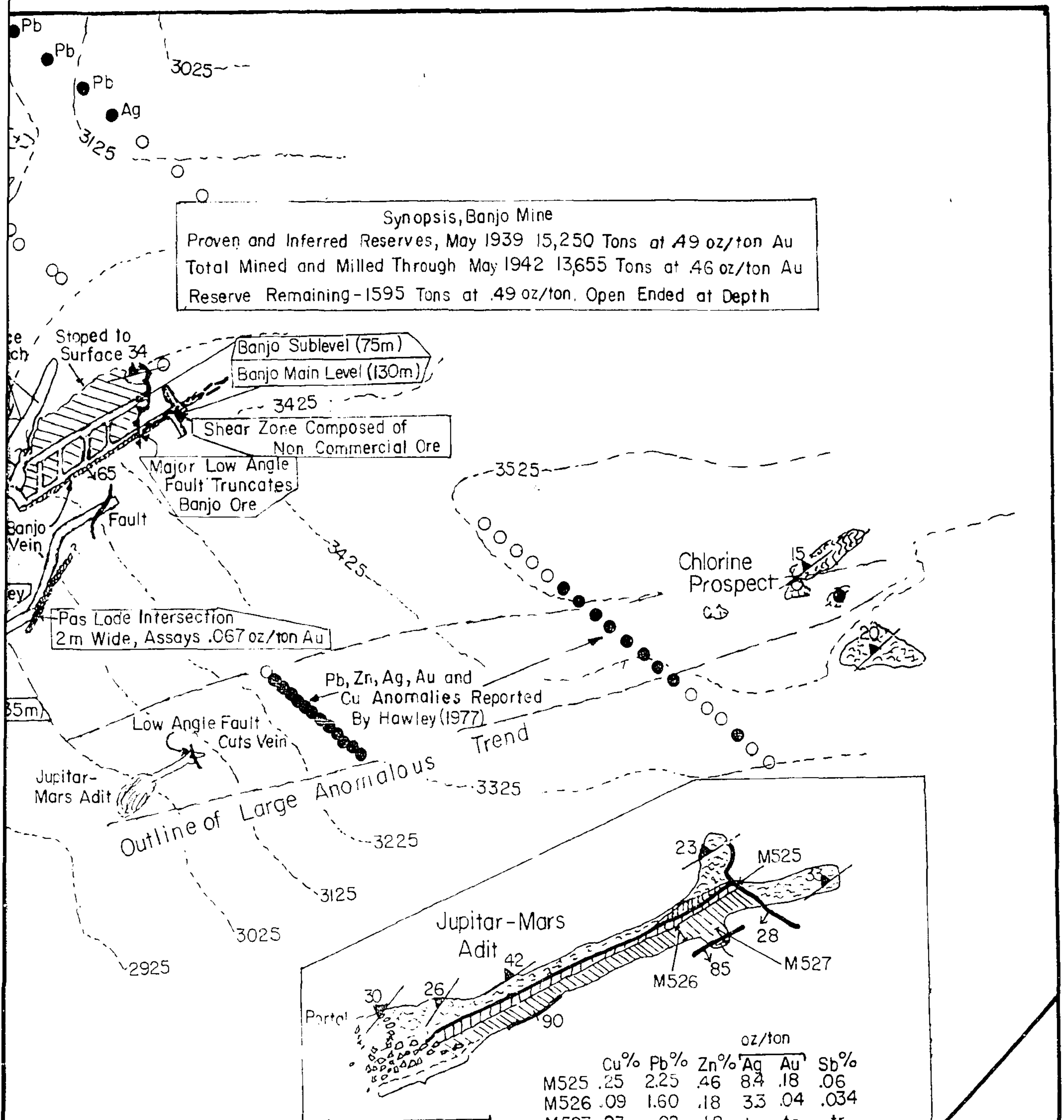
DEPARTMENT O



GEOLOGIC SKETCH OF BANJO LODE SYSTEM SHOWING

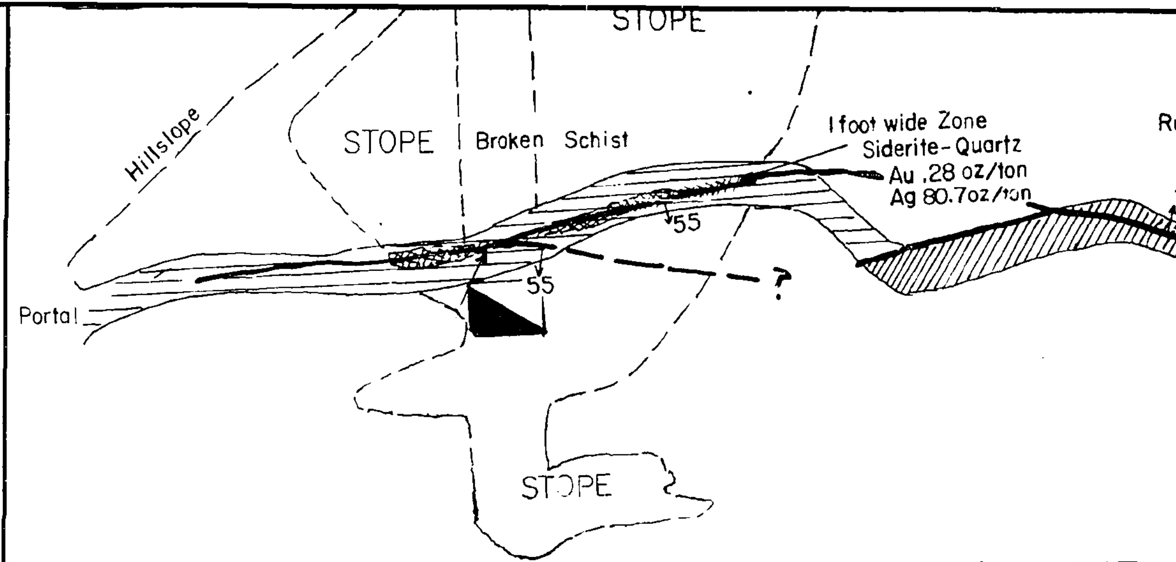
F JUPITAR MARS ADIT from Hawley (1977) Morris (19

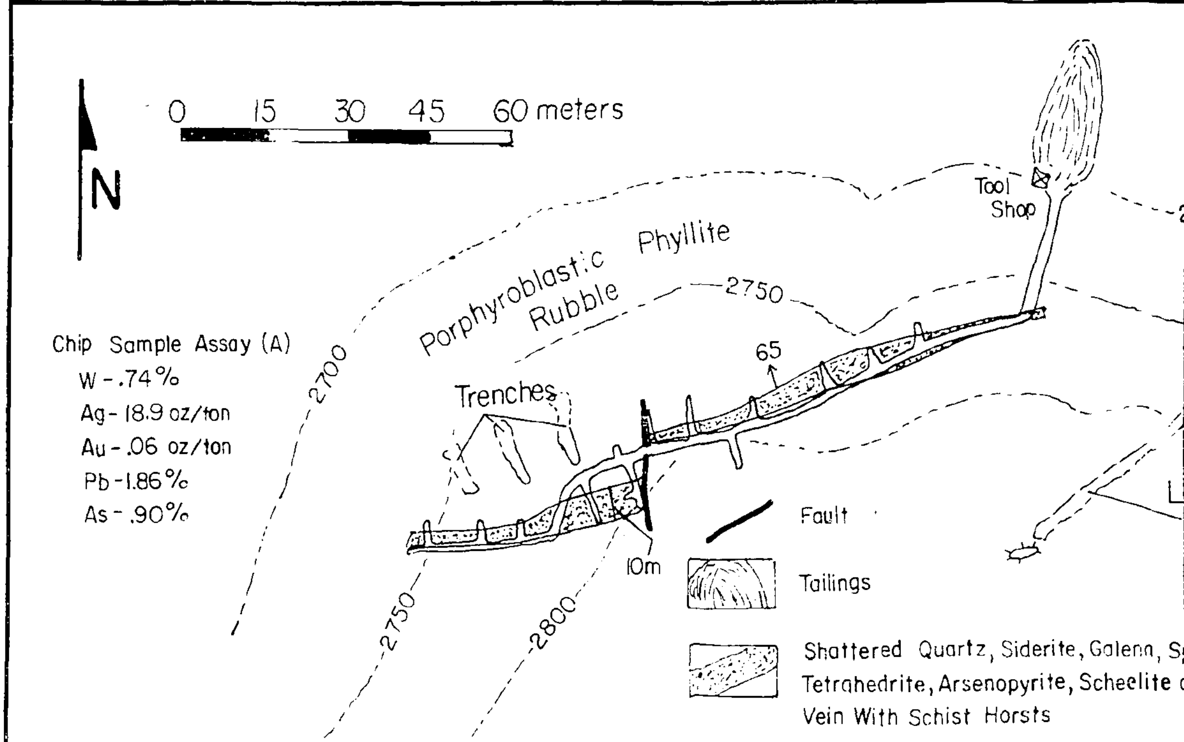
ENT OF GEOLOGY UNIVERSITY OF ALASKA



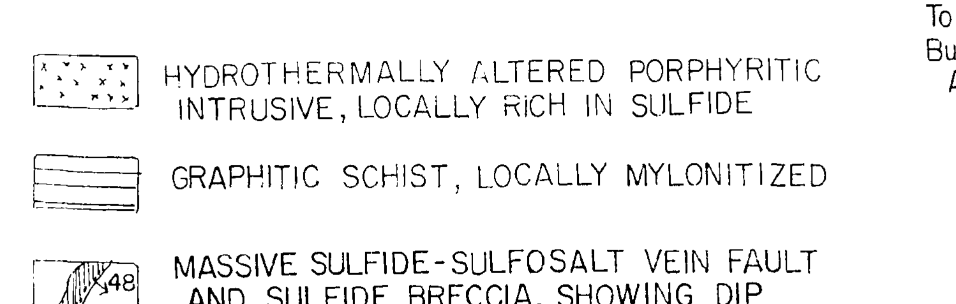
HOWING MAP

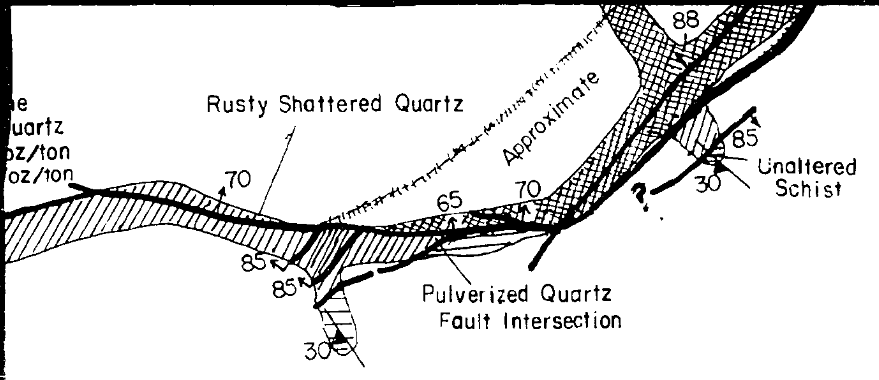
rris (1939),



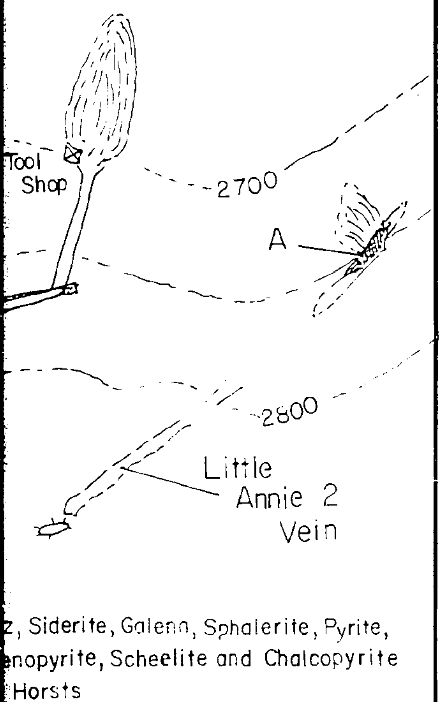


UNDERGROUND WORKINGS, LITTLE AN
MINE after Wells (1933) (prospect 27, p

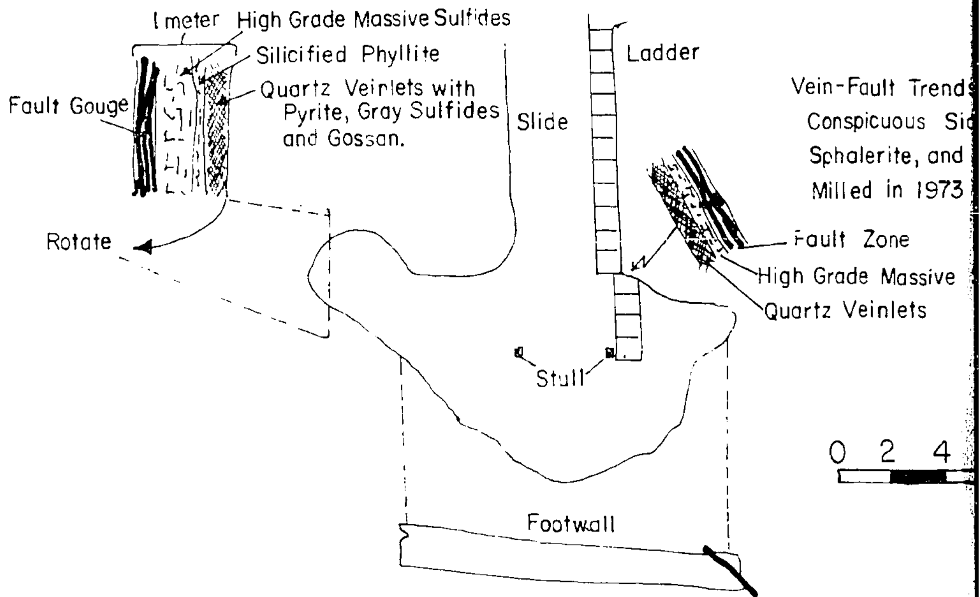




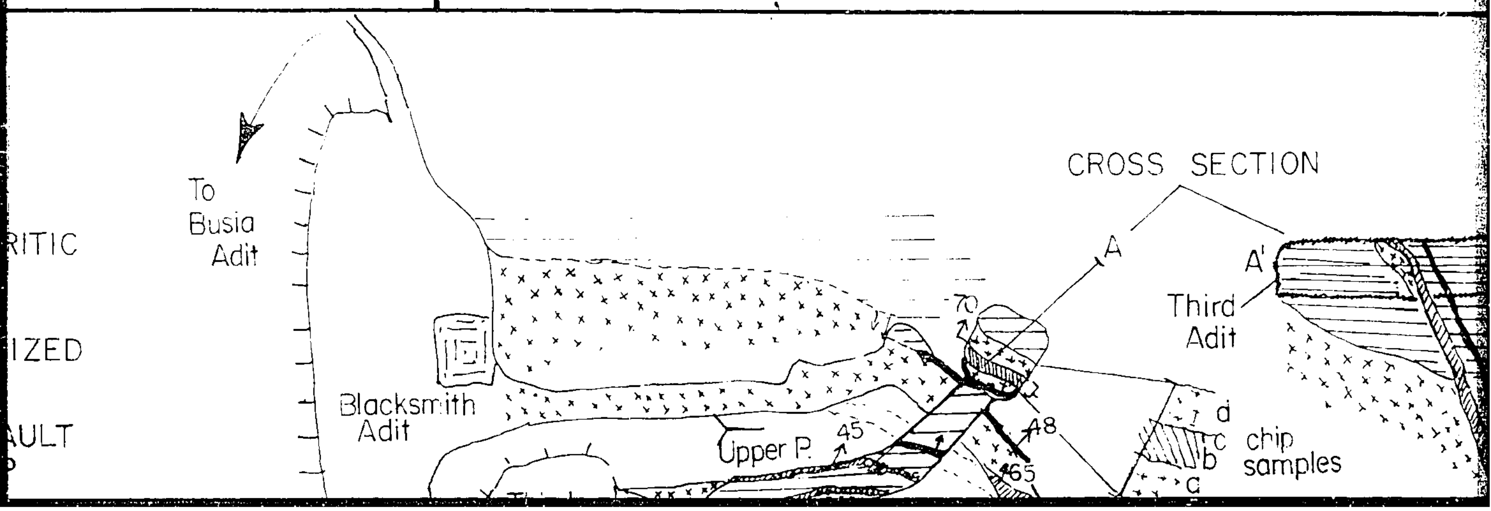
GEOLOGIC MIN
from unpublished
Mining Compan



TTLE ANNIE
pect 27, plate I)



MINE MAP OF GOLD DOLLAR ST
1976 from Hawley (1977) (prospec



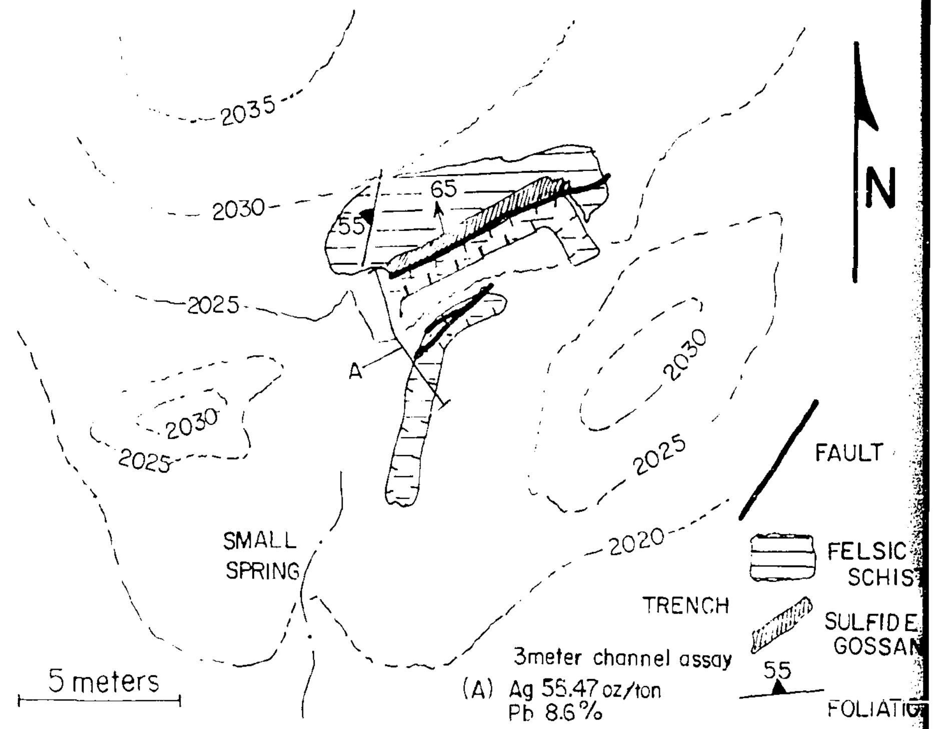
IC MINE MAP OF THE RED TOP MINE
ublished map by Alaska Treadwell Gold
Company (prospect 19, plate I, tables 6,7)

GEOLOG
OF JUP
and this

Vein-Fault Trends N80W 63SW
Conspicuous Siderite, Pyrite, Galena,
Sphalerite, and Tetrahedrite. 120 Tons
Milled in 1973 Averaged 35.0 oz/ton Ag

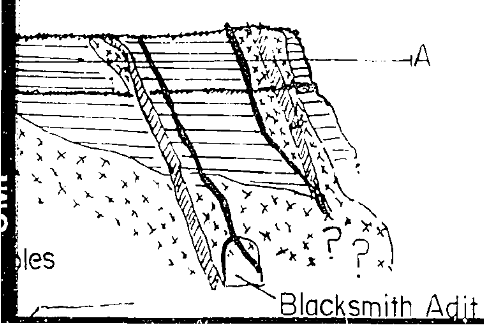
Fault Zone
h Grade Massive Sulfides
artz Veinlets

0 2 4 6 8meters



LAR STOPE IN
prospect 26, plate I)

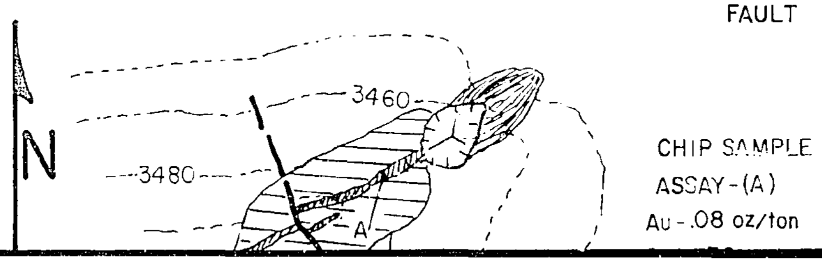
SKETCH OF SILVER KING
LODE (prospect 34, plate I)



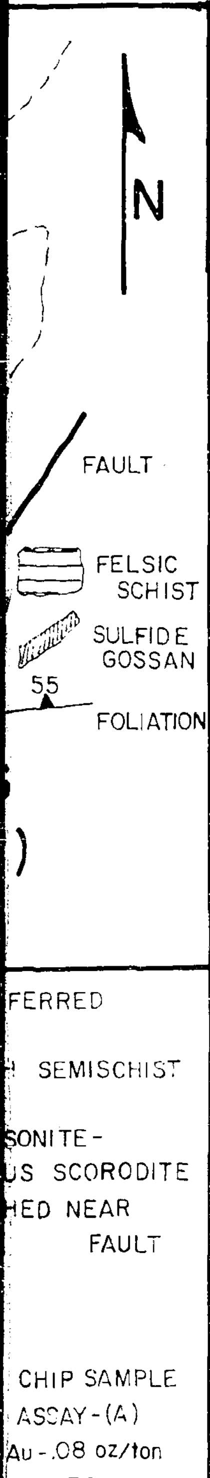
HIGH ANGLE FAULT, DASHED WHERE INFERRED

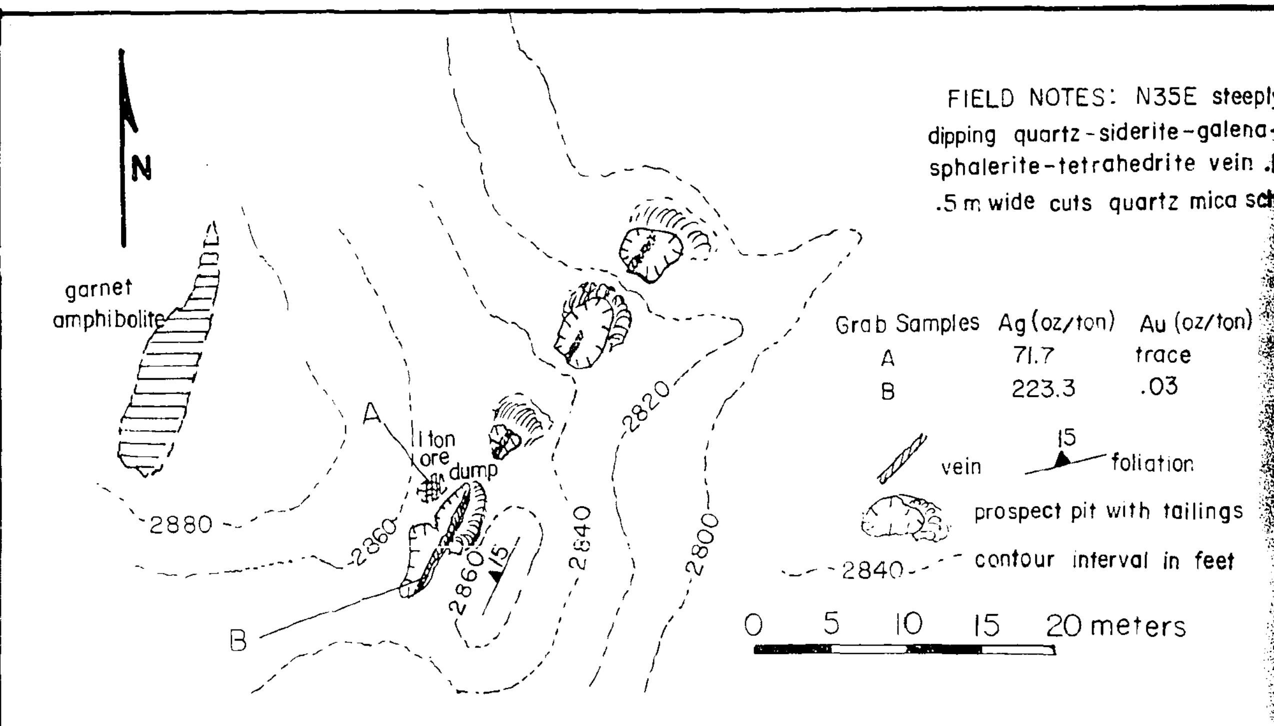
IMPURE MARBLE AND CHLORITE RICH SEMISCHIST

QUARTZ-ARSENOPYRITE-PYRITE-JAMESONITE-
BOULANGERITE VEIN WITH UBIQUTOUS SCORODITE
STAINING; POSSIBLY SULFIDE ENRICHED NEAR
FAULT

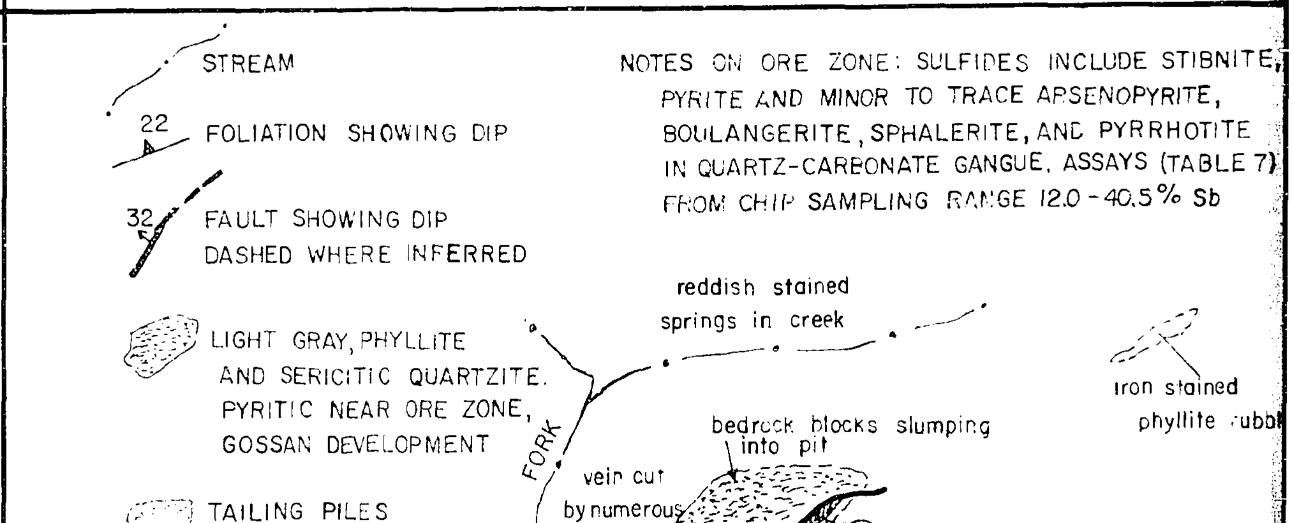


EOLOGIC SKETCH OF BANJO LODE SYSTEM SHOWIN
F JUPITAR-MARS ADIT from Hawley (1977), Morris (193
nd this study (prospects 35,36, plate I, tables 6,7)





SKETCH OF THE BOSART PROSPECT
(prospect 42, plate I, tables 6,7)



HOWING MAP
rris (1939),
)

TES: N35E steeply
tz-siderite-galena-
tetrahedrite vein .l-
cuts quartz mica schist

z/ton) Au (oz/ton)
trace
.3 .03

15
foliation

t pit with tailings

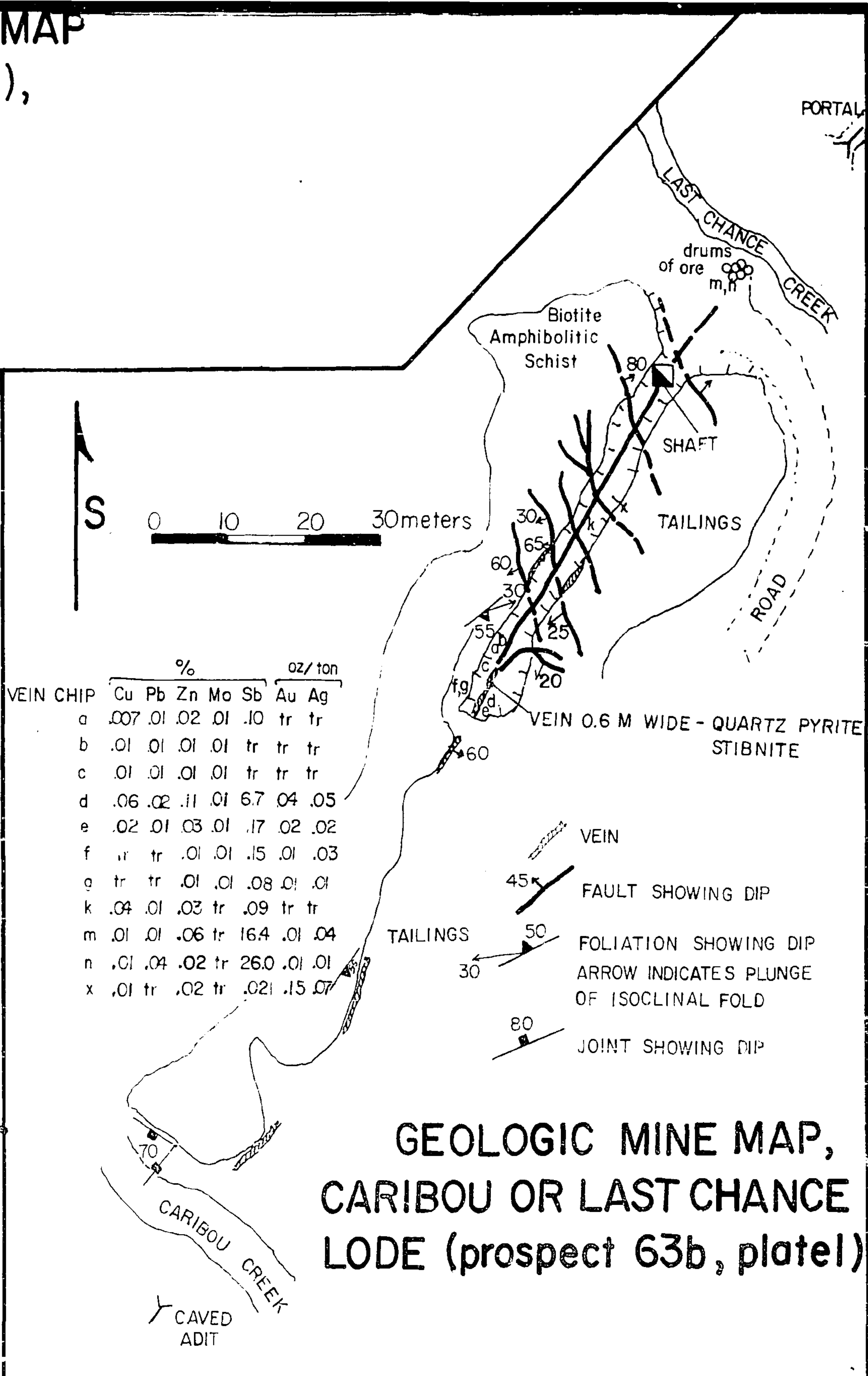
interval in feet

20 meters

PECT
)

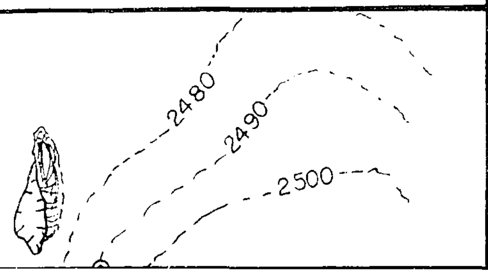
NCLUDE STIBNITE,
RSENOPYRITE,
ND PYRRHOTITE
ASSAYS (TABLE 7)
.0 - 40.5% Sb

iron stained
phyllite rubble



VEIN CHIP	Cu (%)	Pb (%)	Zn (%)	Mo (%)	Sb (%)	Au (oz/ton)	Ag (oz/ton)
a	.007	.01	.02	.01	.10	tr	tr
b	.01	.01	.01	.01	tr	tr	tr
c	.01	.01	.01	.01	tr	tr	tr
d	.06	.02	.11	.01	6.7	.04	.05
e	.02	.01	.03	.01	.17	.02	.02
f	tr	tr	.01	.01	.15	.01	.03
g	tr	tr	.01	.01	.08	.01	.01
k	.04	.01	.03	tr	.09	tr	tr
m	.01	.01	.06	tr	16.4	.01	.04
n	.01	.04	.02	tr	26.0	.01	.01
x	.01	tr	.02	tr	.021	.15	.07

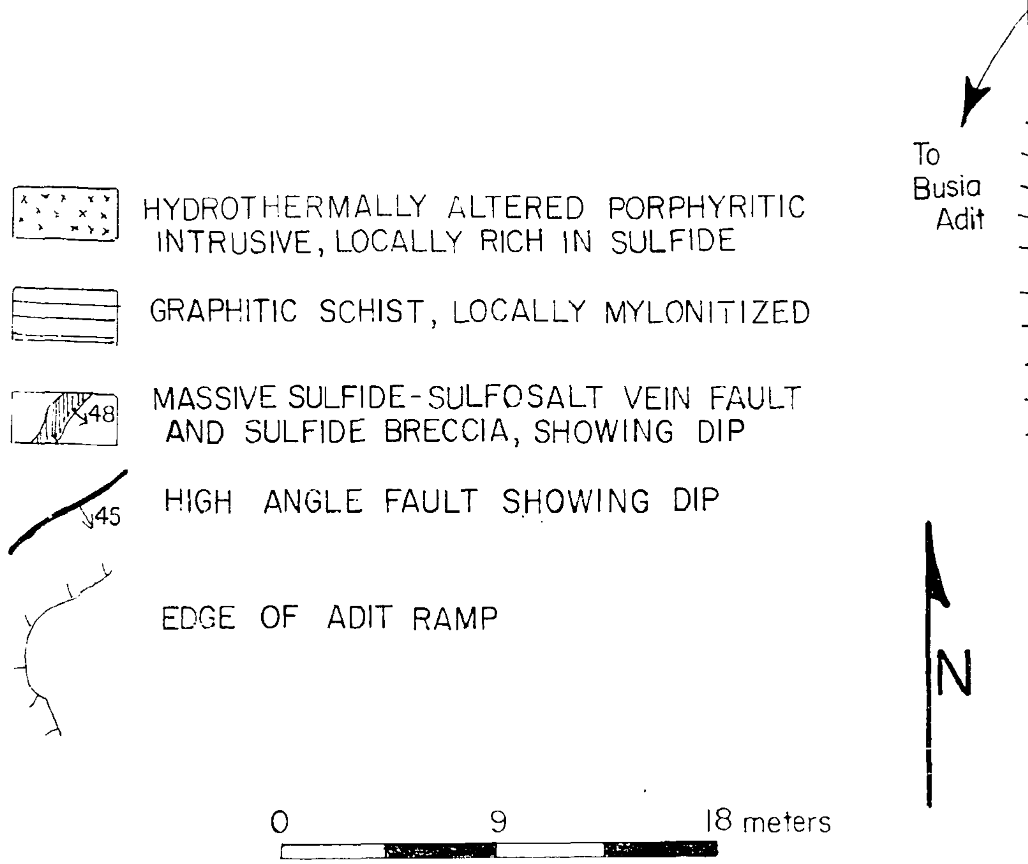
GEOLOGIC MINE MAP, CARIBOU OR LAST CHANCE LODE (prospect 63b, plate1)



GRAY, FINE GRAINED, 'STAMPEDE' QUARTZITE

Tetrahedrite, Arsenopyrite, Scheelite and Ch
Vein With Schist Horsts

UNDERGROUND WORKINGS, LITTLE ANNI
MINE after Wells (1933) (prospect 27, plat

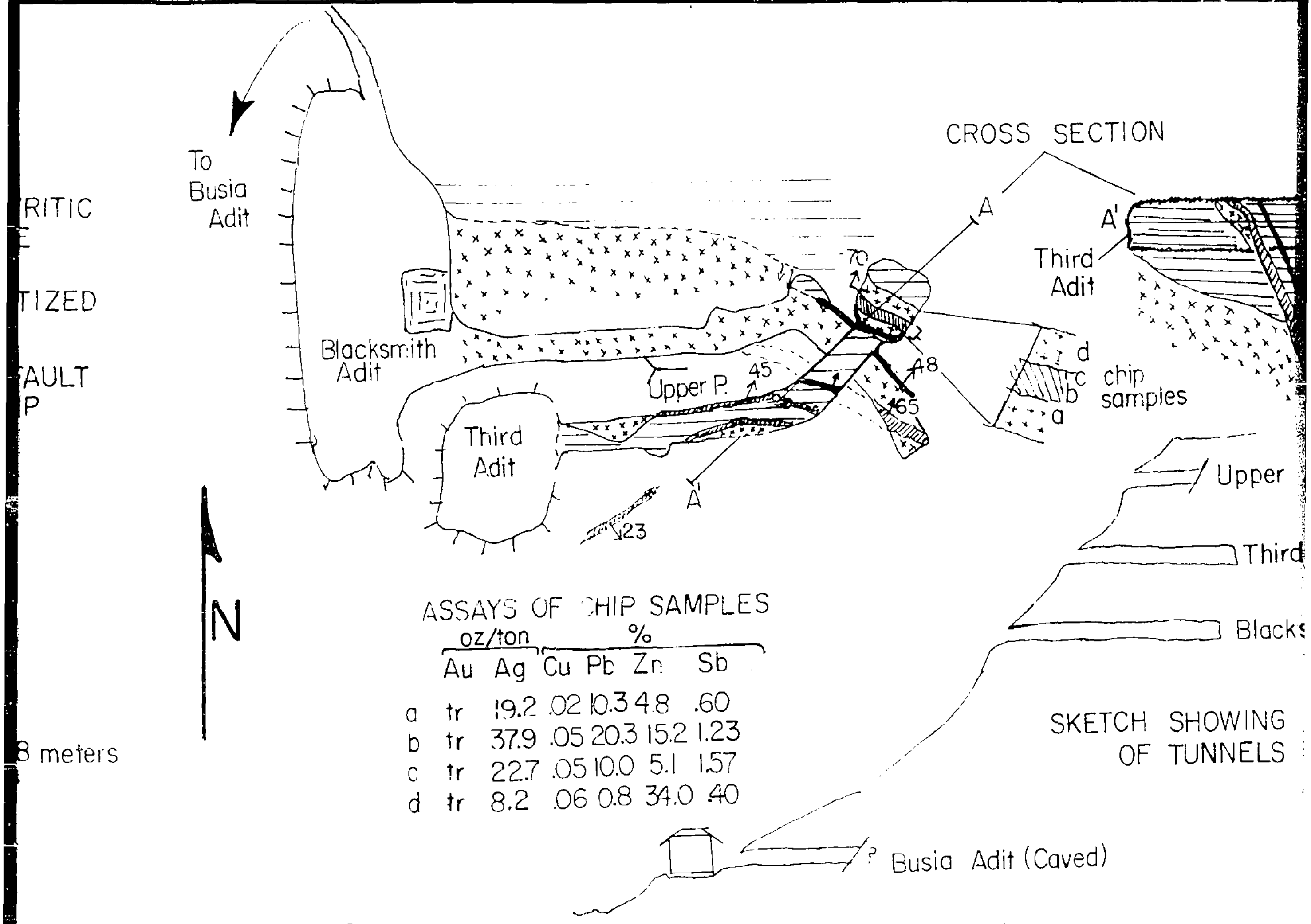


GEOLOGIC MINE MAP OF THE BUNNELL PR
(prospect 4, plate I, tables 6,7)

enopyrite, Scheelite and Chalcopyrite
Horsts

TTLE ANNIE
pect 27, plate I)

MINE MAP OF GOLD DOLLAR ST
1976 from Hawley (1977) (prospec

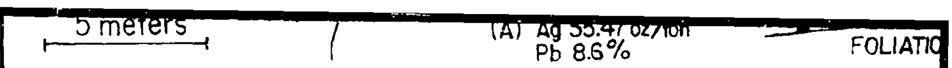


ASSAYS OF CHIP SAMPLES

	oz/ton		%			
	Au	Ag	Cu	Pb	Zn	Sb
a	tr	19.2	.02	10.3	4.8	.60
b	tr	37.9	.05	20.3	15.2	1.23
c	tr	22.7	.05	10.0	5.1	1.57
d	tr	8.2	.06	0.8	34.0	.40

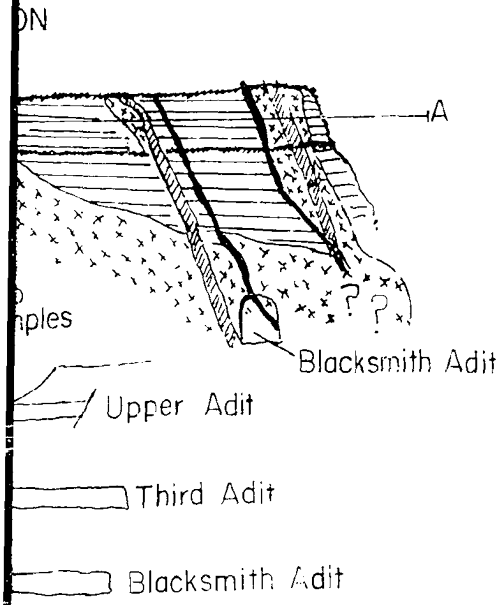
UNNELL PROSPECT

SKETCHES AND MAPS OF

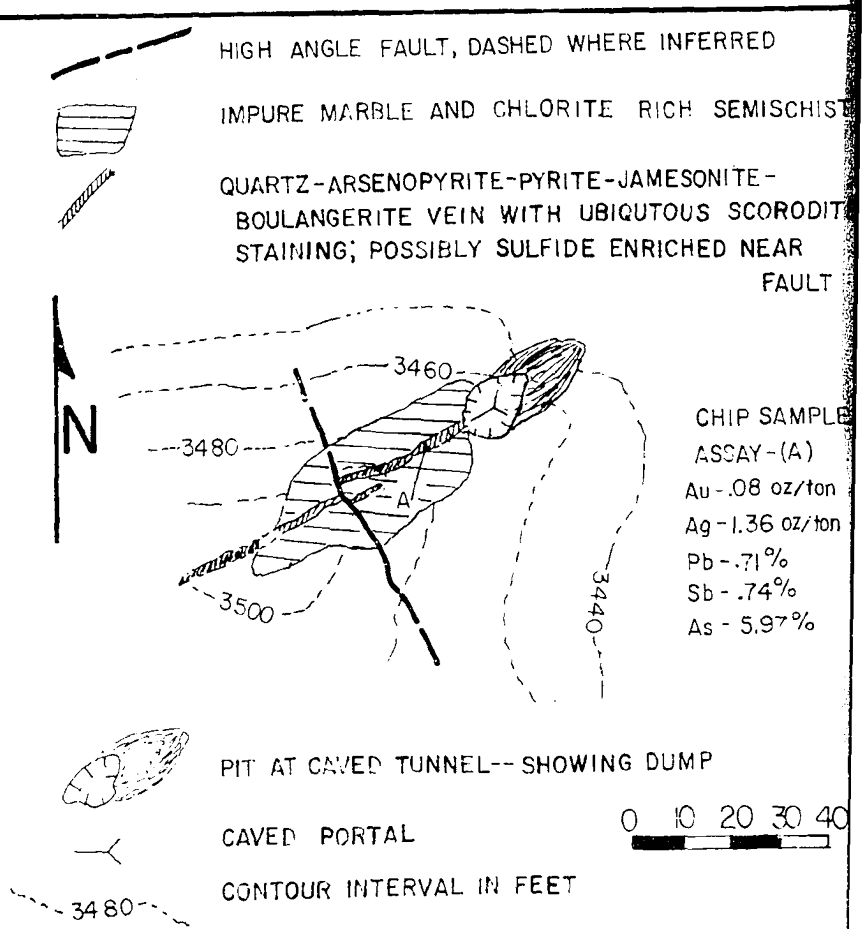


LAR STOPE IN
(prospect 26, platel)

SKETCH OF SILVER KING
LODE (prospect 34, platel)



H SHOWING LOCATION
F TUNNELS



GEOLOGIC SKETCH OF
ARKANSAS PROSPECT
(prospect 55, platel, tables 6,7)

APS OF MINES AND PROSPECTS IN THE KANTIS

Compiled and/or Completed by T.K. Bundtzen

)

(prospect 42, plate I, tables 6,7)

FERRED

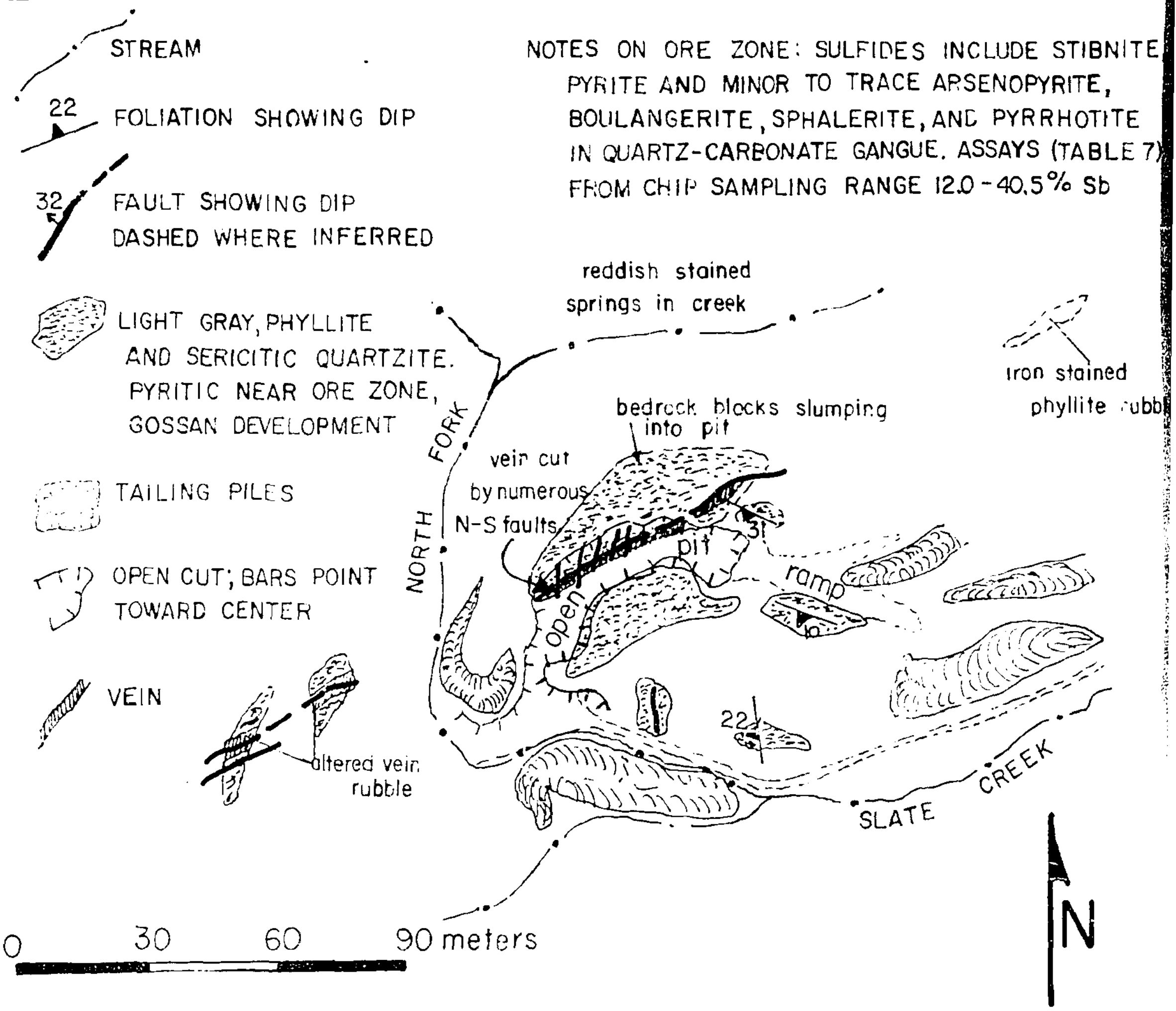
SEMISCHIST

SONITE -
JS SCORODITE
HED NEAR
FAULT

CHIP SAMPLE
ASSAY - (A)
Au - .08 oz/ton
Ag - 1.36 oz/ton
Pb - .71 %
Sb - .74%
As - 5.97 %

MP

0 20 30 40m



GEOLOGIC SKETCH OF SLATE CREEK
OR TAYLOR MINE (prospect I, plate I, tables6,

es 6,7)

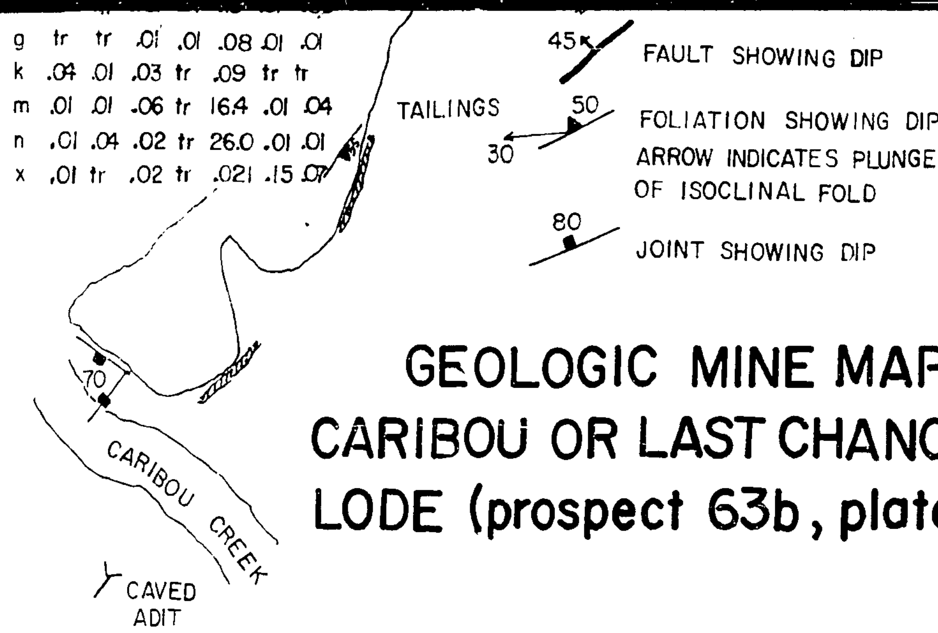
ANTISHNA MINING DISTRICT, ALASKA

ndtzen

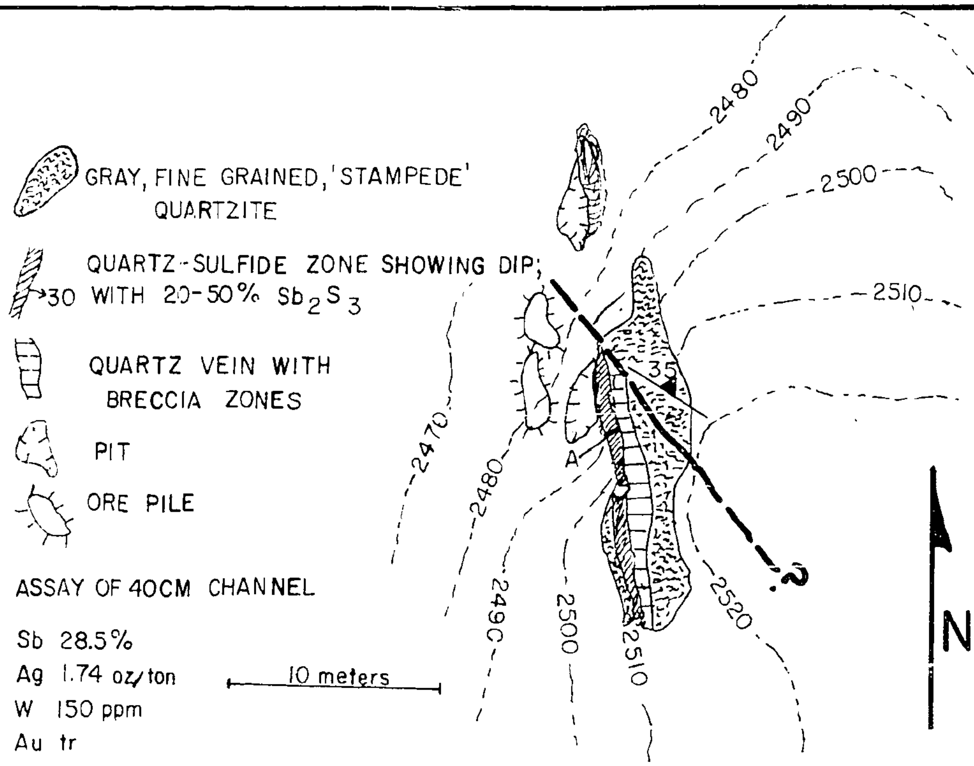
ECT

LUDE STIBNITE,
ENOPYRITE,
PYRRHOTITE
SSAYS (TABLE 7)
-40.5% Sb

EK
(tables 6,7)



GEOLOGIC MINE MAP, CARIBOU OR LAST CHANCE LODE (prospect 63b, plate1)



SKETCH OF MINERALIZED ZONE, EAGLES DEN OR 'DON' ANTIMONY (prospect 6, plate1, tables 6,7)

Department of Geology University of Alaska

Correlation

Late PreCambrian | Paleozoic

Early Paleozoic | Mid to Late Pale

Devonian | Mississipp

m-l Dev

Depositional Sequences

Birch Creek Schist ?

Spruce Creek Sequence ?

Keevy Peak Formation

Totatlanika Schist

Tertiary Sediments

Glacial Till

Terrace Alluvium

Alluvial Fan Deposits

Stream Alluvium

Placer Mine Tailings

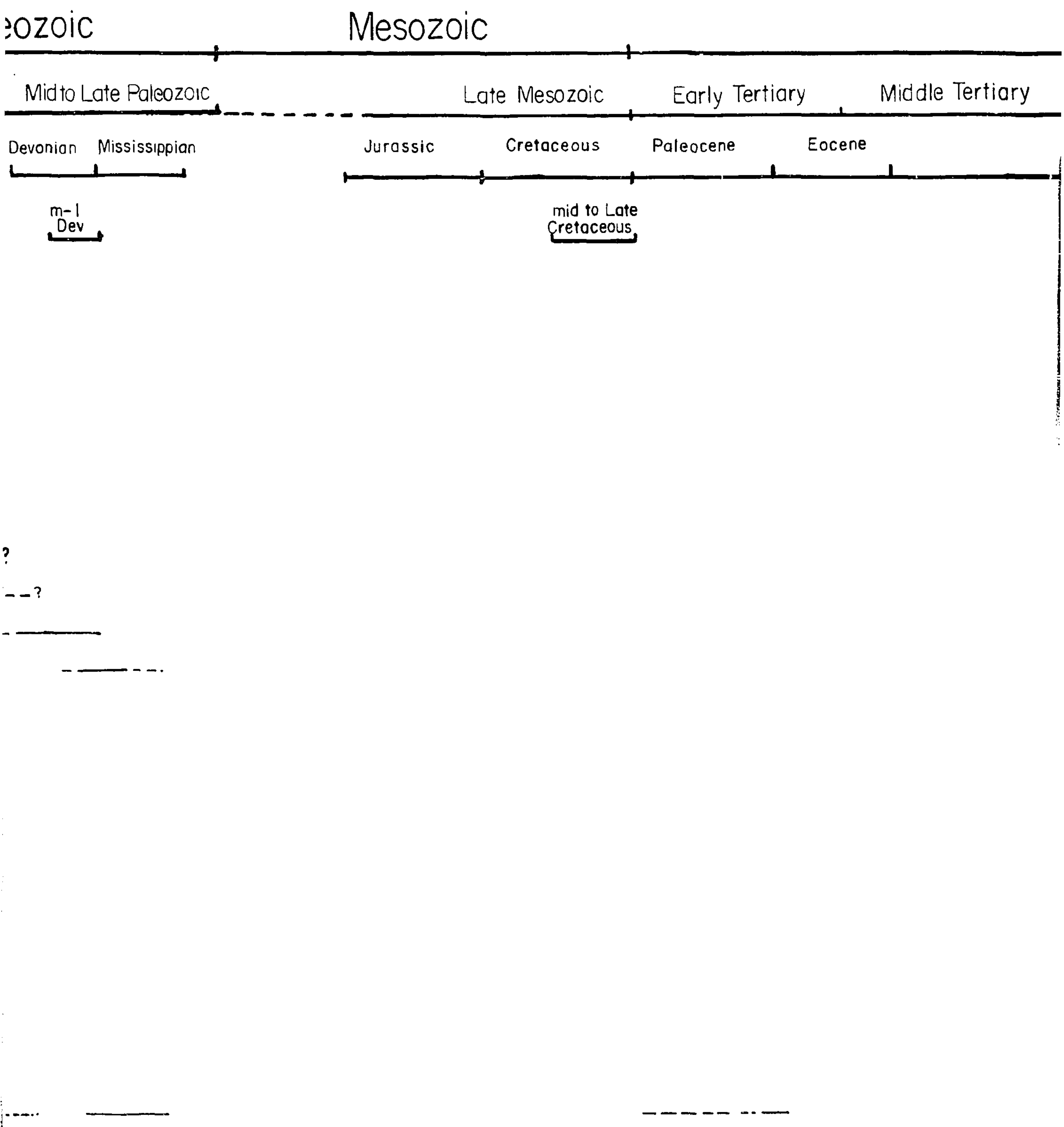
Landslide Debris

Igneous Activity

Volcanism

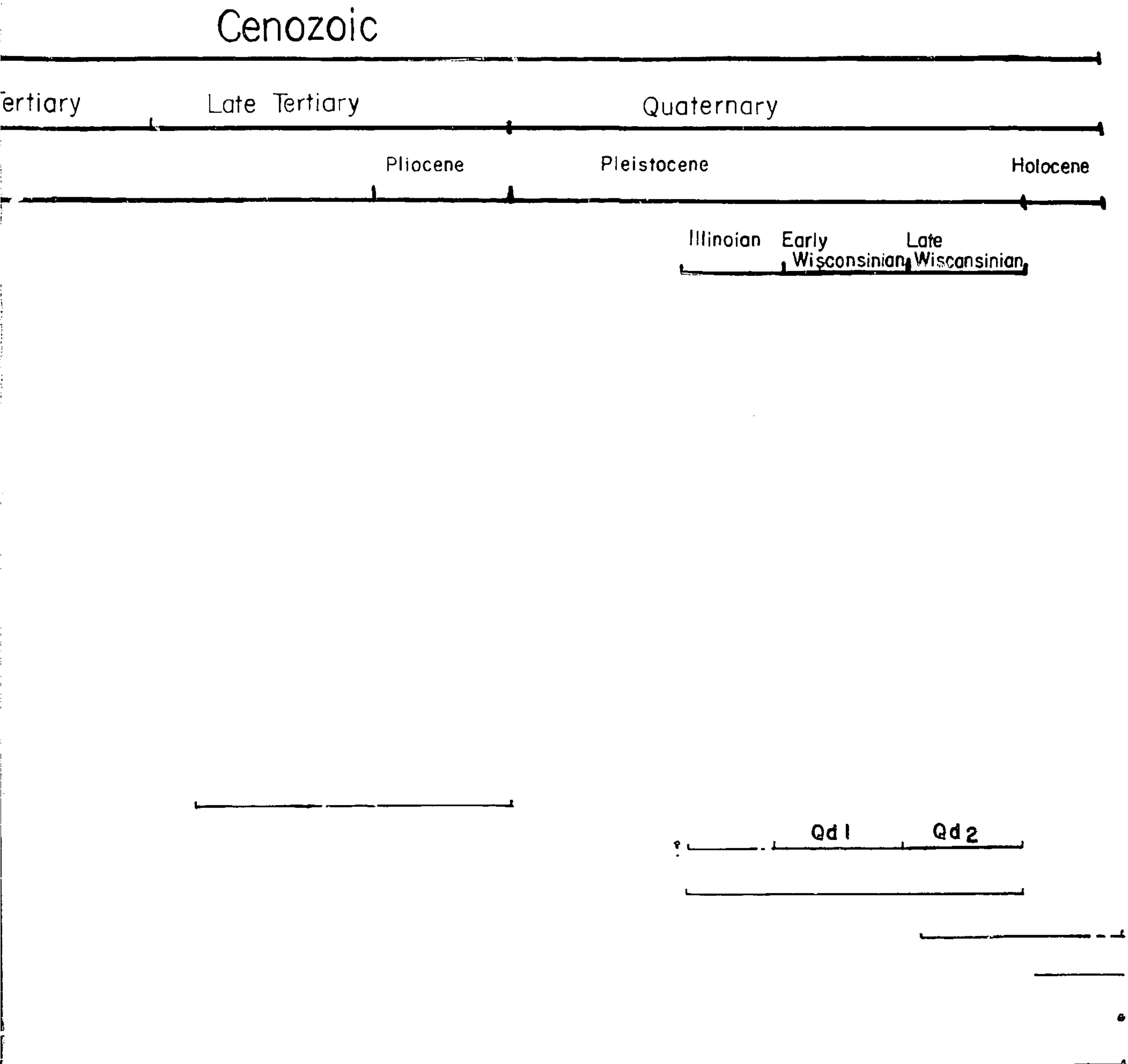
Plutonism

relation Chart Showing Sequence of Geologic Event



Events, Kantishna Hills, Alaska

Plate 4



Tertiary Sediments

Glacial Till

Terrace Alluvium

Alluvial Fan Deposits

Stream Alluvium

Placer Mine Tailings

Landslide Debris

Igneous Activity

Volcanism

Plutonism

Metamorphism

Regional Dynamothermal Metamorphism

Contact Metasomatic or Static Metamorphism

Structure

Cleavege or Foliation S_1, S_2

Folds

Crenulations

High Angle Faults

Thrust Faults

Regional Uplift

Mineralization

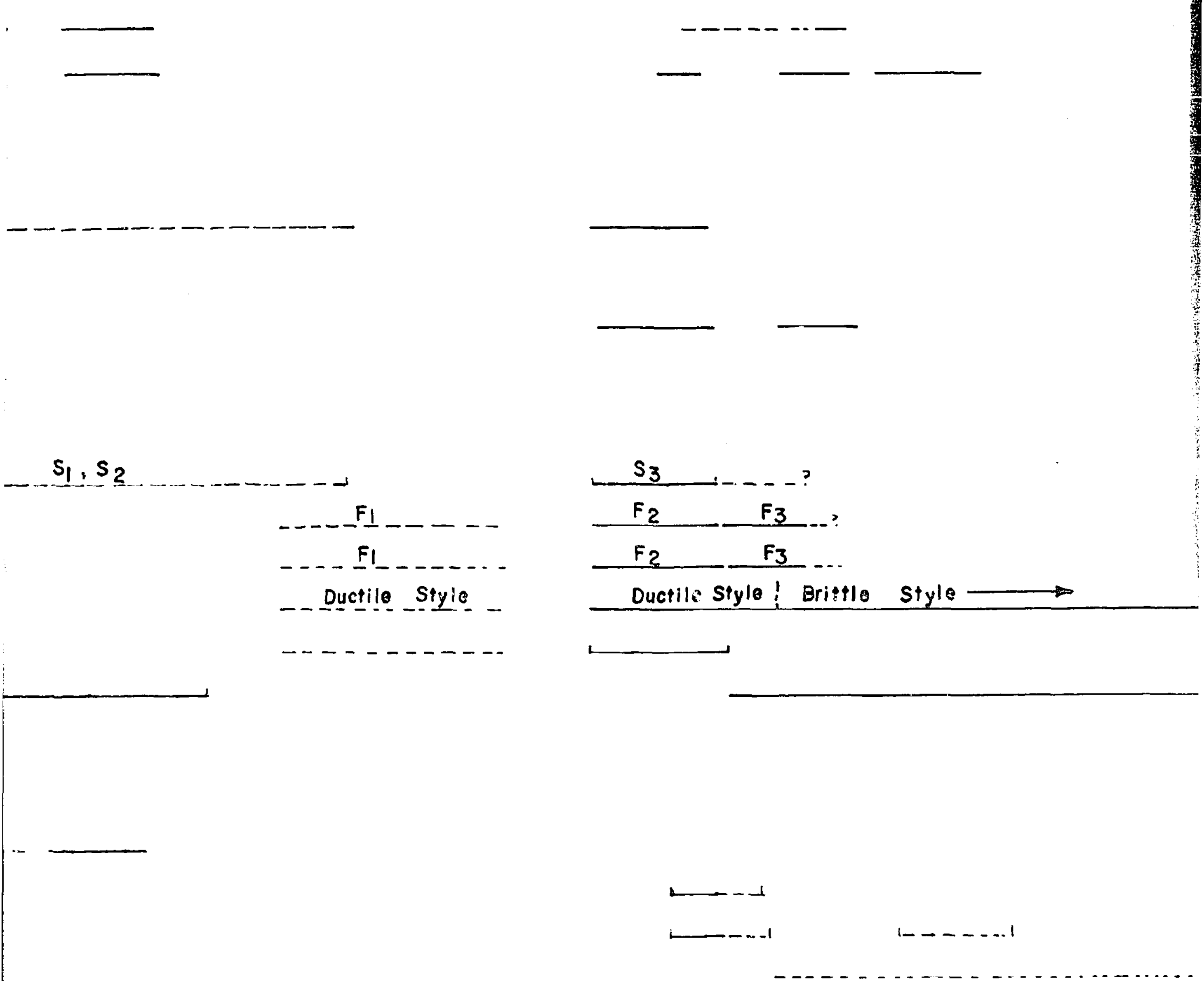
Stratiform Deposits

Vein-Fault Deposits

Skarns

Heavy Mineral (Gold) Placers

Lines Indicate Approximate Duration of Geologic Even



f Geologic Event, Dashed Where Questionable

Qd1 Qd2